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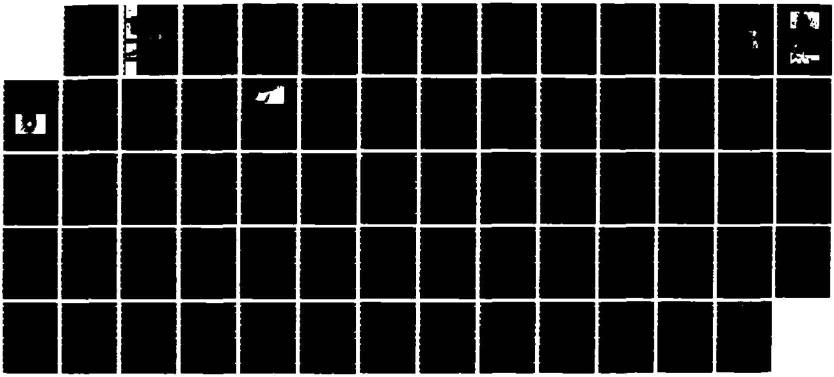

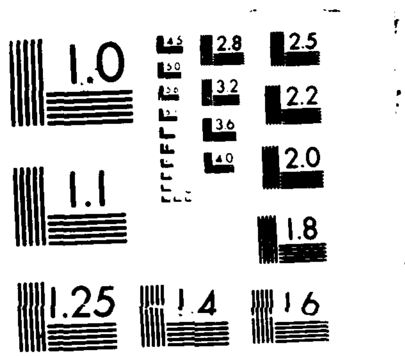

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TECHNICAL REPORT HL-87-2

POST-POOL RAISE SPILLWAY PROTOTYPE TEST FOR CHIEF JOSEPH DAM COLUMBIA RIVER, WASHINGTON

by

T. L. Fagerburg

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

April 1987

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Prototype test data on the hydraulic performance of the standard US Army Corps of Engineers spillway crest at Chief Joseph Dam were obtained following structural modifications to the project required to raise the pool for expansion of hydropower capabilities. These data were correlated with comparable data obtained in model studies of the dam and compared with the data of earlier prototype tests prior to the pool raise. The prototype data consisted of spillway pressure profiles obtained with piezometers, pressure fluctuations indicated by pressure cells embedded in the spillway crest, and vibrations monitored by accelerometers bonded to the trunnion bridge and access gallery floor. The data were obtained at heads of 1.31 and 1.21 times the design head H_d in one gate bay at full and partial gate openings.

Good correlation was found between the model and prototype spillway data for the increased head design. The negative pressures in the prototype generally agreed with

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those predicted in the model. These negative pressures exceeded those obtained in earlier prototype tests primarily due to the increased pool elevation and subsequent higher heads. No significant pressure fluctuations that could cause resonance in the structure were found for any flow condition. No significant vibrations or displacements were evident from the acceleration measurements.

PREFACE

The prototype investigation described herein was conducted during June 1985 by the US Army Engineer Waterways Experiment Station (WES) under the sponsorship of the US Army Engineer District, Seattle.

Acknowledgment is made to the personnel of the Seattle District for their assistance in the investigation. Tests were conducted by Mr. T. L. Fagerburg, Hydraulics Laboratory, WES, under the general supervision of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and M. B. Boyd, Chief of the Hydraulic Analysis Division. This report was prepared by Mr. Fagerburg under the supervision of Mr. E. D. Hart, Chief of the Prototype Evaluation Branch, and edited by Mrs. Marsha Gay, Information Technology Laboratory. Instrumentation support was obtained from Messrs. L. M. Duke, Chief of the Operations Branch, Instrumentation Services Division, and S. W. Guy, Data Acquisition Section.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENTS

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals

POST-POOL RAISE SPILLWAY PROTOTYPE TEST FOR CHIEF JOSEPH DAM
COLUMBIA RIVER, WASHINGTON

PART I: INTRODUCTION

The Project

1. Chief Joseph Dam is located on the Columbia River near the town of Bridgeport in north-central Washington State (Figure 1). The project (Plate 1) includes a 19-bay gated overflow spillway and a 27-unit powerhouse having a total rated capacity of 2,069,000 kw. The project has no fish passage facilities or navigation facilities. The total length of the dam along its axis is 5,960 ft,* and the maximum height above bedrock is approximately 230 ft.

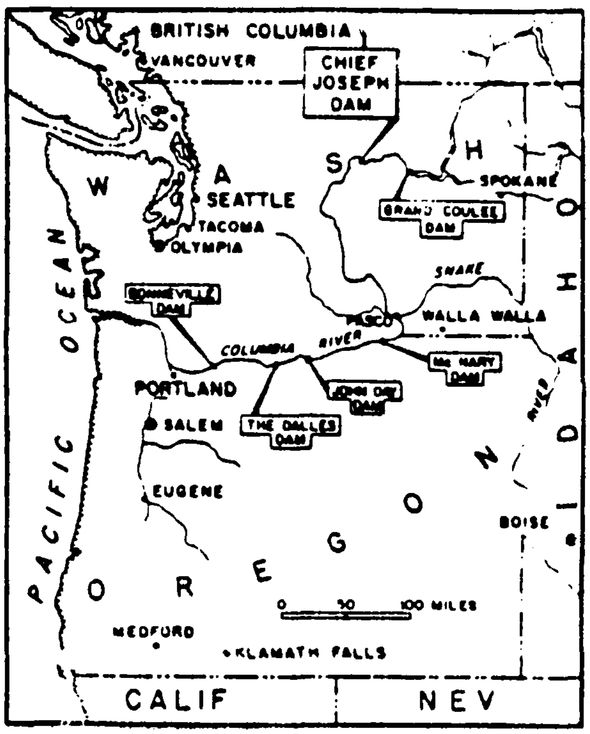

Figure 1. Vicinity map

The Spillway

2. The Chief Joseph Dam spillway was originally designed to pass the spillway design flood at a surcharge el of 956.9** (head of 55.4 ft); however, normal full pool was el 946, which resulted in a head H to design head H_d ratio of 1.07. The crest of the spillway corresponds to the Corps of Engineers high dam shape for the H_d of 41.6 ft. In 1956, the US Army Engineer Waterways Experiment Station (WES) conducted prototype measurements of pressure magnitudes along

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

** All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

the center line, near the pier, and on the pier of one bay of the Chief Joseph spillway at heads ranging from 0.78 to $1.12H_d$.* Prior to these tests, no prototype data on the performance of underdesigned crest shapes had been available.

3. In the 1970's, additional storage was provided on the Columbia River system by construction of upstream dams. The additional storage permitted expansion of the Chief Joseph hydropower generation capability from 16 to 27 turbine-generators with a raise in normal full pool from el 946.0 to 956.0. To accommodate the pool raise, the piers required widening by 4 ft, which narrowed the spillway bays. As a result, narrower and higher gates were fabricated and installed.

4. Prior to the pool raise structural modifications, a model study was conducted at the Hydraulic Laboratory, US Army Engineer Division, North Pacific, to determine the hydraulic characteristics of the spillway with the higher pool elevations.** The model indicated that pressures as low as -5 and -10 ft of water would exist on the spillway crest under free-flow conditions with pool el 956.0 and 958.8, respectively.

5. Details of the existing spillway are shown in Plate 2. The spillway is designed to pass 1,200,000 cfs at an H of approximately 57.3 ft on the crest (reservoir pool el 958.8). Normal full pool elevation is 956.0, which results in a maximum H/H_d ratio of 1.38. The upstream quadrant of the crest shape is a compound curve having radii 0.2 and 0.5 times H_d . The downstream quadrant of the crest conforms to the equation

$$X^{1.85} = 2.0H_d^{0.85}Y$$

where X and Y are defined as the horizontal and vertical distances from the crest origin, respectively.

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* US Army Engineer Waterways Experiment Station. 1958 (Apr). "Prototype Spillway Crest Pressures, Chief Joseph Dam, Columbia River, Washington," Miscellaneous Paper No. 2-266, Vicksburg, Miss.

** US Army Engineer Division, North Pacific. 1979 (May). "Spillway Modifications for Chief Joseph Dam, Columbia River, Washington," Technical Report No. 156-1, Bonneville, Oreg.

Purpose and Scope of Field Tests

Purpose

6. The 10-ft pool raise at Chief Joseph Dam afforded the opportunity to measure prototype spillway crest and pier pressures at H/H_d ratios as high as 1.31. Although model studies of the Chief Joseph Dam spillway with an H/H_d ratio of 1.38 indicated acceptable pressure conditions, uncertainties in the transferring of negative pressure values from model to prototype and construction irregularities that occurred during original spillway crest construction and subsequent pier widening activities made prototype measurements desirable.

Scope

7. The tests included measurements of pressure magnitudes along the spillway center line, near the pier, and on the pier of one spillway bay (bay 9) for partial gate openings and free overflow at heads of $1.21H_d$ and $1.31H_d$. Measurements of structural vibrations were made during the tests at the center line of pier 9 on the trunnion bridge (el 925.0) and at the center line of bay 9 in the service gallery (el 830.0). The measurements from these tests were compared with previous prototype and model information.

8. Six series of tests, performed under different flow conditions, were conducted at Chief Joseph Dam on 31 May and 3 June 1985. Tests were run using gate 9 as the test gate at gate openings of 0.7, 3.8, 8.1, 15.6, and 34.0 ft. An adjacent gate was operated during the 1956 prototype tests. To duplicate this condition, the adjacent gate bay (gate 10) was also used during these tests and operated in the closed position, in the full open position, and at the same gate setting as gate 9. Tests 1-3 were conducted at pool el 956.0 ($1.31H_d$) and tests 4-6 were conducted at pool el 951.6 ($1.21H_d$).

PART II: TFST FACILITIES

Piezometers

9. Twenty-three piezometers were installed in spillway bay 9 during construction. Locations are shown in Plate 3. The piezometer openings were 1/4-in.-diam holes in stainless steel plates fitted to the contour of the concrete surface. Piezometer details are shown in Plate 4. Brass pipes 1/2 in. in diameter connected the openings to three manifolds located in the access gallery with floor el 830. The piezometer manifold is shown in Figure 2 and Plate 5.

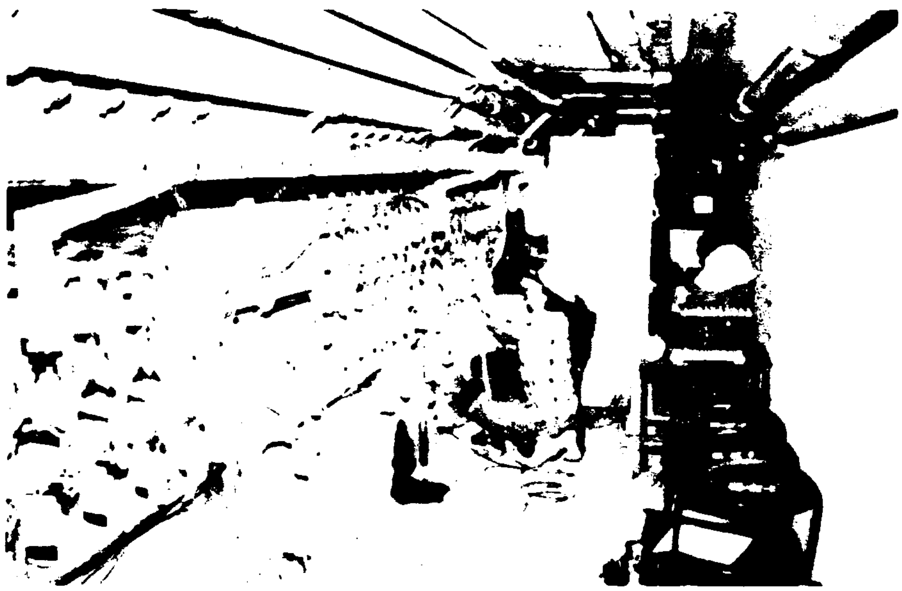

Figure 2. Piezometer manifold

Pressure Cells

10. Recesses for four pressure cells were formed in spillway bay 9 during construction; their locations are shown in Plate 3. Cell A recess was located flush with the concrete surface 5 ft upstream from the gate seat, cell B recess 1 ft upstream, cell C recess 9 ft downstream from the gate, and cell D recess 19 ft downstream from the gate. Commercial-type cells 1/2 in. in diameter were used in the tests and were installed in waterproof adapters as shown in Figure 3 and Plate 4. A 50-psi cell was installed in recesses A

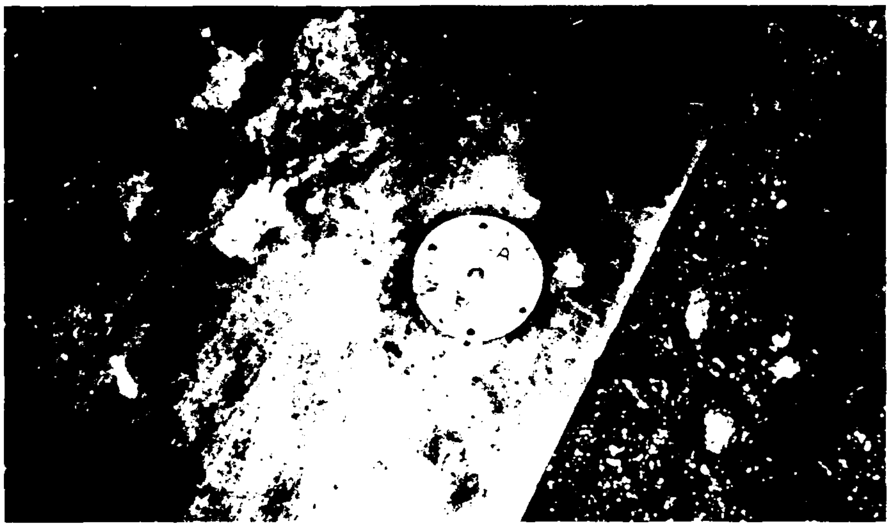

Figure 3. Spillway pressure cell and piezometer

and B; a 25-psi cell was installed in recesses C and D. Before cells A and B could be installed upstream from the spillway crest gate, stop logs had to be placed to an elevation above the reservoir water surface so that the cell recesses would be accessible. The stop logs were placed in the slots by a truck-mounted crane as shown in Figure 4.

11. For the installation, workers wearing safety belts with safety lines attached to the crane cable were lowered onto the spillway face by the

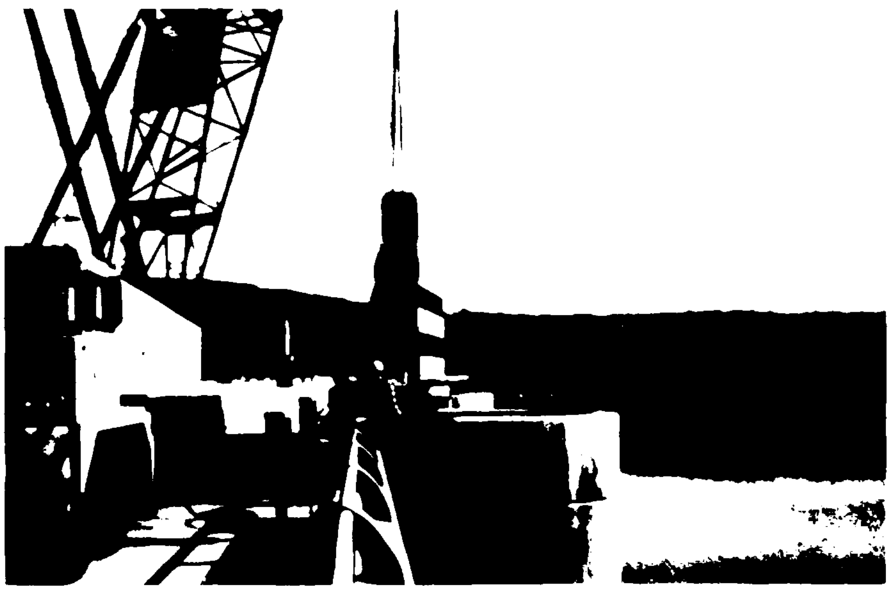

Figure 4. Cranes placing stop logs

crane. Radio communication was established between the access gallery, the catwalk at el 950.0, and the spillway face. The pressure cells were installed by pulling the pressure cell cables through the 1-in. conduit embedded in the concrete to the access gallery at el 830.0 and seating the cells in the recesses. Cells were set flush in the metal housing strip with thin gaskets used as required.

12. Structure vibrations were monitored at two locations on the structure in the vicinity of spillway bay 9. A cluster of three accelerometers was used at each location to measure accelerations in the vertical, transverse (perpendicular to flow), and longitudinal (upstream/downstream) directions. One cluster was located at the center line of pier 14 of spillway bay 9 on the trunnion bridge at el 925.0. An identical cluster was mounted on the floor of the access gallery at el 830.0 and positioned at approximately the center-line location of spillway bay 9. Each cluster was housed in a waterproof canister as shown in Figure 5. The transducer cables from the trunnion bridge location passed to the access gallery recording location through a 12-in.-diam air vent located nearby.

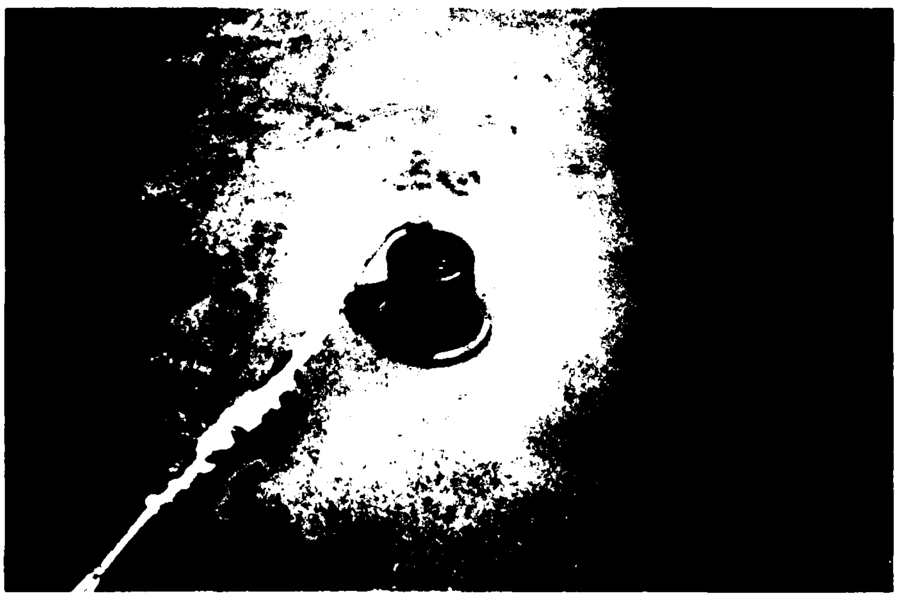

Figure 5. Accelerometer cluster and waterproof canister

Other Measurements

13. Other recorded data consisted of reservoir water-surface elevations, gate opening, and discharge. These data were provided by project personnel and personnel of the US Army Engineer District, Seattle. Water discharge data based on rating curves established for the gates were provided by the Seattle District.

PART III: TEST CONDITIONS AND PROCEDURES

Conditions

14. Measurements were made at pool elevations of about 956.0 and 951.6, or about 1.31 and 1.21 times the H_d of 41.6 ft. Observations were made at various partial gate openings from 0.7 to 34.0 ft (free-overflow condition). The immediately adjacent gate (gate 10) was operated under three conditions: (a) at the same opening as test gate 9, (b) closed, and (c) fully open. Table 1 lists the test conditions.

Procedures

15. The piezometer pipes were flushed and the locations of the piezometer openings and corresponding valves in the gallery were checked prior to removal of the stop logs. Piezometric pressures were observed with CEC unbonded strain gage type pressure cells attached to the manifolds at el 835.0. The pressure cells were calibrated at WES before the tests. Pressures were recorded on magnetic tape and observed on an oscilloscope to ensure that cells were operative. Before each test, the valves to the manifold and pressure cells were carefully opened and any air trapped in the piezometer lines was allowed to bleed off. Piezometer 37 was inoperative throughout the tests so that no data were obtained for that location. Piezometer 34 became inoperative during the lower pool elevation tests. Both lines appeared to be plugged, and efforts to clear the obstructions were unsuccessful. Pressure pulsations were picked up by the pressure cells and recorded on four channels of a 12-channel Racal magnetic tape recorder. All four spillway pressure cells were operational throughout the tests so that continuous data were obtained for all locations. All pressure cells were removed after testing and the cell recess covers replaced.

PART IV: TEST RESULTS

16. All data channels were reduced simultaneously providing a direct time-dependent relationship among all channels. All data reduction was conducted at WES. To reduce the data, a representative 1-min sample of each data channel was selected from each recorded 3-min test. These data were then digitally sampled to provide the following analysis.

Piezometer Data

17. Results of the piezometric measurements are listed in Tables 2-7. Plots of prototype spillway center-line mean pressures for free overflow at H_d values of 1.31, 1.21, and 1.1* are shown in Plate 6. Plates 7-18 show 1985 prototype spillway mean pressures for 0.7-, 3.8-, 8.1-, 15.6-, and 34.0-ft gate openings at H_d values of 1.31 and 1.21. Free overflow was found to exist at a gate opening of 34.0 ft. Available data from the 1956 prototype tests** ($1.0H_d$) or from model studies† ($1.31H_d$) are also presented in Plates 7-18 and are indicated by gate openings of 1.0, 5.0, 10.0 and 15.0 ft. Piezometer readings were converted to elevations to be plotted on these plates. Pressures in the area downstream from the gate were about the same for both pool elevations tested (956.0 and 951.6). When compared with earlier prototype pressures, the spillway pressures downstream of the gate at the higher pool elevations were found to be consistently lower due to the higher heads. The most evident examples at each pool elevation can be seen when free-flow condition is reached at a gate opening of 34.0 ft. As listed in Table 2, minimum mean pressures of about -4.5 ft of water were recorded for the 15.6-ft gate opening and about -6.9 ft of water for the 34.0-ft gate opening at $1.31H_d$ with the adjacent gate 10 closed. This compares with earlier prototype minimum pressures of -1.3 and -0.4, respectively, at $1.0H_d$, at the same conditions. Pressures measured along the center line of the spillway bay differed from those measured along a parallel line 1 ft from the pier. For the free-overflow condition shown in Figure 6, positive pressures on the upstream quadrant of the crest were higher along the center line than near the

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* Data for $1.1H_d$ are from the 1956 prototype tests (WES, op. cit.).
** WES, op. cit.
† US Army Engineer Division, North Pacific, op. cit.

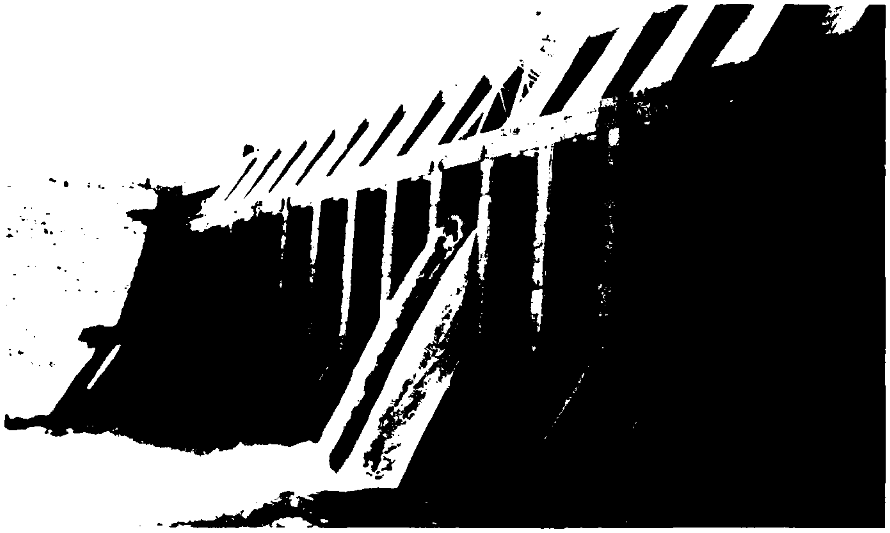


Figure 6. Free-overflow condition through gate bay 9

pier. On the downstream quadrant of the crest, the pressures were generally lower along the center line than near the pier. A comparison of the data in Table 2 with 4 and 5 with 7 for the free-flow condition (gate opening at 34 ft) indicates that pressures upstream of the gate, measured at the spillway center line, are generally lower when the adjacent gate is open. This reduction is probably caused by a change in the flow conditions due to flow passing through the adjacent spillway bay.

18. Plots for comparison of model (Bonneville)* and prototype** center-line spillway pressures at $1.31H_d$ are shown in Plates 11 and 12. Additional model studies were used (Maynord 1985† and Melsheimer and Murphy 1970††) for comparison of center-line and pier pressures, shown in Plates 19 and 20. Model and prototype center line of gate bay pressures for all comparable tests were found to be in general agreement as indicated in the plates and as anticipated from the Froude law. The prototype data for the pressures along the

* US Army Engineer Division, North Pacific, op. cit.

** WES, op. cit.

† S. T. Maynord. 1985 (Mar). "General Spillway Investigation; Hydraulic Model Investigation," Technical Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

†† E. S. Melsheimer and T. E. Murphy. 1970 (Jan). "Investigations of Various Shapes of the Upstream Quadrant of the Crest of a High Spillway; Hydraulic Laboratory Investigation," Research Report H-70-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

pier agreed more closely with the model from the 1979 Bonneville study than with the other models (Maynord, Melsheimer and Murphy). The large differences, primarily in the upstream crest area, between the latter models and the prototype are largely due to significant differences in the local geometry (crest shapes and pier lengths). The upstream crest curvature in the prototype was not as sharp as those used in the models (Maynord, Melsheimer and Murphy) and the pier in the prototype extends approximately 6 ft beyond the upstream face of the dam, compared with the pier in the model, which was flush with the upstream face. These two unique features would explain the large difference between pressures of the prototype and the models.

Pressure Cell Data

19. The pressure cells were used to indicate the magnitude and frequency of the fluctuations on the crest. The highest, lowest, and mean pressures were determined from the digitized data time-histories along with the maximum instantaneous peak-to-peak pressure fluctuation for each test. The predominant frequencies of the pressure recordings were determined by transforming the data from the time domain to the frequency domain with a mathematical Fourier Transform (or Fast Fourier Transform (FFT)). These mean pressures and frequencies are listed in Tables 8-13. These pressure fluctuations were of small magnitude and irregular frequency, varying from 0.2 to 3.1 ft of water at frequencies of 1 to 32 Hz. The lowest mean and low pressures recorded were -6.9 and -8.0 ft respectively (Table 8). The pattern of pressure fluctuations is of the turbulence type and indicates no difference in interpretation from that observed from earlier prototype test records. The crest pressure fluctuations shown in Plate 21 illustrate that for the 3.8- and 8.1-ft gate openings, the turbulent boundary layer developed rapidly between cells B and C. For the 15.6-ft opening, the boundary layer was developing in the range from cell A through cell C when the adjacent gate was fully open. For the condition of free overflow, the turbulent boundary layer appears to have been well developed upstream from cell A.

20. Pressure fluctuations recorded did not indicate a tendency towards stable, sinusoidal pulsations. At a head of 54.5 ft ($1.31H_d$), the gate lip separated from the flow at an opening of 34 ft. The flow conditions at the water surface upstream of the gate were extremely turbulent when the gate lip

approached within 4 ft of breaking free of the water surface. Tests were recorded with the gate reentering the flow; however, no significant differences in pressure recordings could be identified.

21. With no sinusoidal fluctuations or pulsations being observed for any flow condition, there appears to be no significant forcing vibration that could cause resonance in the structure with the low velocity of approach at this high dam.

Vibration of Structure

22. Vibrations were measured at el 925.0 on the trunnion bridge and at el 830.0 on the access gallery floor directly beneath the center line of spillway bay 9. Tables 14-19 list the trunnion bridge accelerations and Tables 20-25 list the access gallery floor accelerations. The tables list the greatest instantaneous maximum, minimum, and peak-to-peak accelerations along with the predominant frequency of fluctuation and displacement. The sinusoidal displacements were estimated by the equation:

$$d = \frac{(32.2)\ (\text{acceleration})}{(2\pi\ \text{freq})^2}$$

where

d = peak-to-peak sinusoidal displacement, ft

acceleration = greatest peak-to-peak acceleration, g's

freq = predominant frequency, Hz

23. In general, the vibrations were insignificant in all tests. Peak-to-peak accelerations in the transverse direction appeared to be highest on the trunnion bridge at maximum gate opening (34.0 ft) with the adjacent gate at the same opening during tests at pool el 956.0 (Table 19). The displacements of the trunnion bridge (Tables 14-19), particularly those in the transverse direction, are probably the result of the vertical flexing occurring at the center of the trunnion bridge, which spans the spillway bays between adjoining piers. However, no measurements were taken at that location to verify that this is the condition that exists. The displacements of the access gallery (Tables 20-25) are so small that they can be considered to be insignificant.

PART V: CONCLUSIONS AND RECOMMENDATIONS

24. The following conclusions and recommendations are based on analyses of the findings of the tests described in this report:

a. Good correlation exists between the Chief Joseph Dam model and prototype data.

b. Mean and instantaneous pressures as low as -6.9 ft and -8.0 ft of water, respectively, were measured on the spillway center line at an H/H_d ratio of 1.31. These low pressures, which exceed those of the first test period, are primarily due to the higher spillway heads. The minimum mean pressure measured from the model for similar conditions was -7.0 ft of water.

c. No significant pressure fluctuations or pulsations that could cause resonance in the structure were found for any flow condition.

d. Considerable turbulence occurs upstream of the gate when the gate lip approaches to within about 4 ft of breaking free of the upper nappe. It is recommended that gate operations between 30 and 34 ft be avoided unless absolutely necessary.

e. In general, most of the vibrations and displacements computed from acceleration measurements were insignificant. The trunnion bridge displacements were largest in the transverse direction and appear to be the result of the vertical flexing of the trunnion bridge span between adjoining piers. The displacements computed from the access gallery vibrations were all very small.

Table 1

Test Conditions

Date	Test No.	Gate 9 Opening, ft	Gate 10 Opening, ft	Discharge cfs	Pool El ft
31 May	1A	0.7	0.0	960	956.0
	1B	3.8	0.0	5,430	
	1C	8.1	0.0	11,360	
	1E	15.6	0.0	21,300	
	1H	34.0	0.0	57,500	
	2A	0.7	34.0	58,460	
	2B	3.8	34.0	62,930	
	2C	8.1	34.0	68,860	
	2E	15.6	34.0	78,800	
	3A	0.7	0.7	1,920	
	3B	3.8	3.8	10,860	
	3C	8.1	8.1	22,720	
	3E	15.6	15.6	42,600	
	3H	34.0	34.0	115,000	
3 June	4A	0.7	0.0	920	951.6
	4B	3.8	0.0	5,200	
	4C	8.1	0.0	10,850	
	4E	15.6	0.0	20,260	
	4H	34.0	0.0	49,500	
	5A	0.7	34.0	50,420	
	5B	3.8	34.0	54,700	
	5C	8.1	34.0	60,350	
	5E	15.6	34.0	69,760	
	6A	0.7	0.7	1,840	
	6B	3.8	3.8	10,400	
	6C	8.1	8.1	21,700	
	6E	15.6	15.6	40,520	
	6H	34.0	34.0	99,000	

Table 2

Spillway Piezometer Pressures

Adjacent Gate Closed

Pool El 956.0

$H/H_d = 1.31$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water Test 1A Gate Open 0.7 ft	Test 1B Gate Open 3.8 ft	Test 1C Gate Open 8.1 ft	Test 1E Gate Open 15.6 ft	Test 1H Gate Open 34.0 ft
C-1	896.5	59.5	58.6	57.2	51.2	23.1
C-3	899.1	57.0	55.3	52.3	44.9	11.2
C-5	900.9	54.8	53.3	48.2	39.6	6.7
C-7	901.5	54.5	50.4	45.3	34.9	10.2
C-8	900.9	54.2	41.3	27.4	17.3	-1.2
C-9	900.0	32.9	12.2	11.6	8.0	-2.6
C-10	896.1	0.7	-0.9	-2.8	-3.5	-4.2
C-11	890.1	0.5	-0.6	-1.8	-4.5	-6.9
C-12	882.2	0.0	0.6	0.0	-2.1	-2.7
C-13	872.3	0.0	1.5	1.1	0.0	-0.6
C-14	860.5	0.0	0.7	1.4	0.6	0.8
C-34	896.5	59.5	56.8	57.2	53.8	33.2
C-37	900.2	Piezometer Plugged				
C-38	900.9	54.1	41.7	28.8	21.0	2.5
C-40	901.5	54.0	52.0	43.7	31.0	-3.4
C-41	900.9	54.3	41.8	30.7	21.9	4.3
C-42	900.0	29.7	16.3	15.4	13.1	3.4
C-43	896.1	0.0	-1.8	-1.1	-2.2	-2.2
P-50	899.7	56.3	55.2	51.7	48.5	23.1
P-20	921.5	34.6	34.1	33.3	30.7	11.4
P-38	911.5	44.5	43.3	39.9	31.8	12.2
P-56	902.5	53.5	50.7	44.4	33.2	1.4
P-58	898.4	0.5	-0.6	-0.5	-0.6	0.5

* See Plate 3 for location.

Table 3

Spillway Piezometer Pressures

Adjacent Gate Full Open

Pool El 956.0

$H/H_d = 1.31$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water Test 2A Gate Open 0.7 ft	Test 2B Gate Open 3.8 ft	Test 2C Gate Open 8.1 ft	Test 2E Gate Open 15.6 ft
C-1	896.5	59.5	56.3	52.6	47.5
C-3	899.1	54.9	53.2	50.0	41.9
C-5	900.9	53.6	51.7	47.3	37.6
C-7	901.5	54.4	52.1	42.9	30.5
C-8	900.9	52.9	39.6	25.1	16.3
C-9	900.0	32.0	12.6	10.3	8.0
C-10	896.1	0.6	-1.0	-2.3	-1.2
C-11	890.1	0.5	0.0	-0.9	-2.2
C-12	882.2	0.0	0.5	0.7	-1.2
C-13	872.3	0.0	1.7	1.3	1.1
C-14	860.5	0.1	1.8	1.8	1.5
C-34	896.5	57.6	56.6	55.3	50.7
C-37	900.2	Piezometer Plugged			
C-38	900.9	53.0	41.3	30.2	21.4
C-40	901.5	52.8	49.3	42.0	28.2
C-41	900.9	52.9	41.3	29.3	21.0
C-42	900.0	28.8	16.3	14.0	13.1
C-43	896.1	0.0	-1.2	-1.8	-1.8
P-50	899.7	54.6	54.0	52.7	47.7
P-20	921.5	33.1	33.1	33.2	30.1
P-38	911.5	42.4	42.7	39.7	31.7
P-56	902.5	51.7	48.9	43.3	31.4
P-58	898.4	0.1	0.5	+0.9	1.7

* See Plate 3 for location.

Table 4

Spillway Piezometer Pressures

Adjacent Gate at Same Opening

Pool El 956.0

$H/H_d = 1.31$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water Test 3A Gate Open 0.7 ft	Test 3B Gate Open 3.8 ft	Test 3C Gate Open 8.1 ft	Test 3E Gate Open 15.6 ft	Test 3H Gate Open 34.0 ft
C-1	896.5	59.3	58.4	56.0	50.5	16.1
C-3	899.1	56.4	34.1	52.5	44.5	6.6
C-5	900.9	54.8	53.4	49.1	39.4	3.9
C-7	901.5	54.5	51.8	44.9	30.7	1.0
C-8	900.9	54.3	41.3	26.5	17.6	-3.0
C-9	900.0	34.3	11.7	9.4	8.5	-3.1
C-10	896.1	0.9	-1.1	-2.5	-3.0	-4.2
C-11	890.1	-0.2	0.5	-1.9	-4.2	-3.2
C-12	882.2	-0.1	0.5	-0.5	-1.8	-2.5
C-13	872.3	0.1	1.4	1.2	0.0	-0.3
C-14	860.5	0.0	1.6	1.8	0.9	1.7
C-34	896.5	58.8	58.3	56.9	52.9	28.1
C-37	900.2			Piezometer Plugged		
C-38	900.9	54.1	43.6	31.6	21.7	0.7
C-40	901.5	53.1	50.2	42.7	31.4	-1.8
C-41	900.9	54.2	42.6	30.6	22.8	3.9
C-42	900.0	29.7	15.4	14.9	13.6	4.3
C-43	896.1	0.0	-1.0	-1.8	-1.8	-1.2
P-50	899.7	56.3	55.0	53.4	48.8	20.8
P-20	921.5	34.2	33.8	32.9	29.8	12.4
P-38	911.5	44.2	43.1	40.0	31.9	13.6
P-56	902.5	52.6	50.3	43.8	33.4	0.4
P-58	898.4	0.1	0.3	0.9	2.1	-0.5

* See Plate 3 for location.

Table 5

Spillway Piezometer Pressures

Adjacent Gate Closed

Pool El 951.6

$H/H_d = 1.21$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water: Test 4A Gate Open 0.7 ft	Test 4B Gate Open 3.8 ft	Test 4C Gate Open 8.1 ft	Test 4E Gate Open 15.6 ft	Test 4H Gate Open 34.0 ft
C-1	896.5	55.0	54.9	53.3	48.5	25.9
C-3	899.1	52.4	52.1	49.6	43.3	15.0
C-5	900.9	50.5	49.8	46.0	37.7	10.5
C-7	901.5	50.0	47.2	39.0	29.2	4.9
C-8	900.9	50.5	38.8	26.3	18.3	3.1
C-9	900.0	32.1	14.6	11.8	11.4	2.6
C-10	896.1	0.9	-0.5	-2.3	-1.8	-1.4
C-11	890.1	-0.2	-1.4	-3.7	-5.8	-5.1
C-12	882.2	0.2	1.2	0.0	-0.9	-0.9
C-13	872.3	0.5	1.7	1.1	0.9	1.2
C-14	860.5	0.3	2.8	1.4	2.3	2.8
C-34	896.5	Piezometer Plugged				
C-37	900.2	Piezometer Plugged				
C-38	900.9	50.1	47.4	40.9	30.3	2.2
C-40	901.5	49.8	47.1	40.3	29.7	0.6
C-41	900.9	49.8	38.6	27.5	20.6	5.4
C-42	900.0	28.0	16.0	14.6	13.7	5.8
C-43	896.1	0.0	-0.6	-1.2	-1.1	0.0
P-50	899.7	51.6	51.2	49.5	45.5	21.3
P-38	911.5	40.0	38.3	36.3	29.4	12.8
P-56	902.5	48.5	46.2	40.7	31.0	4.2
P-58	898.4	0.0	0.3	0.9	2.6	0.7
P-20	899.7	29.8	29.6	29.0	26.0	10.2

* See Plate 3 for location.

Table 6

Spillway Piezometer Pressures

Adjacent Gate Full Open

Pool El 951.6

$H/H_d = 1.21$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water: Test 5A Gate Open 0.7 ft	Test 5B Gate Open 3.8 ft	Test 5C Gate Open 8.1 ft	Test 5E Gate Open 15.6 ft
C-1	896.5	55.0	53.8	51.1	45.5
C-3	899.1	52.4	51.2	47.7	40.4
C-5	900.9	50.6	48.3	44.3	35.6
C-7	901.5	50.0	46.6	38.2	26.9
C-8	900.9	50.5	38.6	24.8	16.0
C-9	900.0	32.6	14.6	11.8	10.4
C-10	896.1	0.8	-0.5	-1.2	-1.4
C-11	890.1	1.7	1.4	0.9	-0.9
C-12	882.2	0.4	0.9	0.9	0.0
C-13	872.3	0.9	1.8	1.8	1.1
C-14	860.5	0.6	1.4	2.3	2.3
C-34	896.5	Piezometer Plugged			
C-37	900.2	Piezometer Plugged			
C-38	900.9	49.4	47.4	40.7	29.1
C-40	901.5	49.5	46.3	39.6	28.3
C-41	900.9	49.3	37.5	26.4	19.0
C-42	900.0	26.1	15.0	13.2	12.7
C-43	896.1	0.0	-0.9	-1.2	-0.9
P-50	899.7	51.3	50.6	49.0	44.2
P-38	911.5	40.0	39.1	36.5	28.5
P-56	902.5	49.0	45.2	40.9	29.6
P-58	898.4	0.0	0.0	0.9	2.0
P-20	899.7	29.5	29.4	28.8	26.2

* See Plate 3 for location.

Table 7

Spillway Piezometer Pressures

Adjacent Gate at Same Opening

Pool El 951.6

$H/H_d = 1.21$

Piezometer No.*	Piezometer El	Mean Pressure, ft of water Test 6A Gate Open 0.7 ft	Test 6B Gate Open 3.8 ft	Test 6C Gate Open 8.1 ft	Test 6F Gate Open 15.6 ft	Test 6H Gate Open 34.0 ft
C-1	896.5	55.0	55.0	53.1	46.9	19.5
C-3	899.1	52.4	51.5	49.5	41.7	10.4
C-5	900.9	50.6	50.0	46.0	36.3	7.2
C-7	901.5	50.0	47.7	40.1	26.9	2.5
C-8	900.9	50.5	39.2	26.1	17.4	1.2
C-9	900.0	33.0	14.1	12.7	10.9	2.6
C-10	896.1	0.9	-0.7	-1.8	-2.1	-1.8
C-11	890.1	3.5	3.2	0.3	-1.4	-0.9
C-12	882.2	0.3	0.9	0.2	-0.7	-0.9
C-13	872.3	0.9	1.8	1.9	1.2	0.9
C-14	860.5	0.5	1.6	2.3	2.3	2.3
C-34	896.5	Piezometer Plugged				
C-37	900.2	Piezometer Plugged				
C-38	900.9	50.6	48.1	41.7	30.8	2.2
C-40	901.5	49.8	47.0	39.8	29.2	0.6
C-41	900.9	49.7	38.1	26.6	20.1	5.4
C-42	900.0	27.5	15.5	14.1	13.2	5.8
C-43	896.1	0.0	-0.5	-1.4	-0.9	0.0
P-50	899.7	51.8	51.8	49.5	44.9	21.3
P-38	911.5	40.0	40.0	36.3	28.5	13.2
P-56	902.5	49.0	46.7	40.7	30.5	5.2
P-58	898.4	0.0	0.5	0.9	2.3	0.9
P-20	899.7	30.0	29.8	29.1	26.3	10.9

* See Plate 3 for location.

Table 8

Spillway Pressures and Pressure Fluctuations

Adjacent Gate Closed

$H/H_d = 1.31$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
1A	956.0	0.7	A	54.3	54.2	54.0	0.2	2
			B	33.4	32.9	32.7	0.6	1
			C	1.1	0.7	-0.2	1.4	2
			D	1.4	0.5	0.3	1.0	2
1B	956.0	3.8	A	41.5	41.3	41.1	0.4	3
			B	12.5	12.2	11.9	0.5	1
			C	0.8	-0.9	-1.6	1.4	20
			D	0.3	-0.6	-1.5	1.8	10
1C	956.0	8.1	A	27.6	27.4	27.2	0.4	2
			B	11.8	11.6	11.2	0.5	3
			C	-1.8	-2.8	-3.7	1.8	10
			D	0.9	-1.8	-2.7	1.8	10
1E	956.0	15.6	A	17.6	17.3	17.0	0.6	2
			B	8.4	8.0	7.6	0.7	2
			C	-2.6	-3.5	-4.3	1.4	13
			D	-3.3	-4.5	-5.1	1.8	2
1H	956.0	34.0	A	-0.4	-1.2	-2.0	1.4	8
			B	-1.6	-2.6	-3.5	1.8	6
			C	-3.0	-4.2	-5.1	2.1	6
			D	-6.0	-6.9	-8.0	1.8	8

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 9

Spillway Pressures and Pressure Fluctuations

Adjacent Gate Full Open

$H/H_d = 1.31$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
2A	956.0	0.7	A	53.2	52.9	52.8	0.4	2
			B	33.4	32.0	30.3	2.9	2
			C	1.6	0.6	-0.9	2.3	4
			D	1.4	0.5	0.2	1.0	4
2B	956.0	3.8	A	40.0	39.6	39.3	0.5	8
			B	13.0	12.6	12.4	0.5	4
			C	-0.2	-1.0	-1.7	1.6	2
			D	1.1	0.0	-0.7	1.7	8
2C	956.0	8.1	A	26.0	25.1	24.4	1.3	2
			B	11.2	10.3	9.8	1.2	2
			C	-1.1	-2.3	-3.2	2.1	8
			D	0.5	-0.0	-2.0	2.3	4
2E	956.0	15.6	A	17.0	16.3	15.8	1.2	2
			B	8.7	8.0	7.2	1.4	2
			C	0.7	-1.2	-1.9	2.6	8
			D	0.0	-2.2	-3.2	3.1	4

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 10

Spillway Pressures and Pressure Fluctuations

Adjacent Gate at Same Opening

$H/H_d = 1.31$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
3A	956.0	0.7	A	54.4	54.3	54.2	0.2	7
			B	34.4	34.3	34.2	0.2	4
			C	1.7	0.9	0.3	1.3	21
			D	0.4	-0.2	-0.4	0.8	7
3B	956.0	3.8	A	41.4	41.3	41.1	0.2	2
			B	12.0	11.7	11.5	0.5	6
			C	-0.2	-1.1	-2.1	1.7	20
			D	1.4	0.5	-0.3	1.2	6
3C	956.0	8.1	A	26.7	26.5	26.3	0.3	4
			B	9.7	9.4	9.2	0.4	20
			C	-1.6	-2.5	-3.4	1.4	10
			D	-1.0	-1.9	-2.6	1.6	6
3E	956.0	15.6	A	18.0	17.6	17.4	0.4	2
			B	8.9	8.5	8.2	0.7	7
			C	-2.0	-3.0	-3.6	1.5	10
			D	-3.4	-4.2	-5.1	1.5	4
3H	956.0	34.0	A	-2.3	-3.0	-3.6	1.2	8
			B	-2.3	-3.1	-3.8	1.2	5
			C	-3.0	-4.2	-5.0	1.7	8
			D	-2.1	-3.2	-4.2	1.8	5

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 11

Spillway Pressures and Pressure Fluctuations

Adjacent Gate Closed

$H/H_d = 1.21$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
4A	951.6	0.7	A	50.8	50.5	49.9	0.8	2
			B	32.2	32.1	32.0	0.2	1
			C	1.7	0.9	0.2	1.2	7
			D	0.4	-0.2	-0.4	0.7	1
4B	951.6	3.8	A	38.9	38.8	38.6	0.2	2
			B	14.8	14.6	14.5	0.3	10
			C	0.2	-0.5	-1.0	1.0	2
			D	-0.4	-1.4	-2.0	1.1	2
4C	951.6	8.1	A	26.4	26.3	26.0	0.4	6
			B	12.0	11.8	11.5	0.4	14
			C	-1.3	-2.3	-3.0	1.4	3
			D	-2.7	-3.7	-4.4	1.1	14
4E	951.6	15.6	A	18.5	18.3	18.1	0.3	1
			B	11.7	11.4	11.2	0.5	1
			C	-0.8	-1.8	-2.5	1.4	10
			D	-4.8	-5.8	-6.3	1.4	8
4H	951.6	34.0	A	3.6	3.1	2.5	0.8	32
			B	3.4	2.6	2.1	1.1	8
			C	0.2	-1.4	-2.1	1.7	31
			D	-4.1	-5.1	-6.0	1.4	8

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 12

Spillway Pressures and Pressure Fluctuations

Adjacent Gate Full Open

$H/H_d = 1.21$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
5A	951.6	0.7	A	50.7	50.5	50.4	0.2	8
			B	33.2	32.6	31.8	1.2	2
			C	1.7	0.8	-0.6	1.8	1
			D	2.4	1.7	1.2	1.0	1
5B	951.6	3.8	A	38.7	38.6	38.3	0.4	8
			B	14.8	14.6	14.3	0.4	12
			C	0.1	-0.5	-1.3	1.3	12
			D	2.1	1.4	0.7	1.4	2
5C	951.6	8.1	A	25.1	24.8	24.5	0.5	2
			B	12.3	11.8	11.5	0.6	1
			C	-0.2	-1.2	-2.1	1.2	2
			D	1.6	0.9	0.0	1.0	2
5E	951.6	15.6	A	16.5	16.0	15.6	0.9	3
			B	10.7	10.4	9.7	0.8	3
			C	-0.2	-1.4	-2.2	1.3	3
			D	0.5	-0.9	-1.8	2.2	10

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 13

Spillway Pressures and Pressure Fluctuations

Adjacent Gate at Same Opening

$H/H_d = 1.21$

Test No.	Pool El	Gate Opening ft	Pressure Transducer	Pressure, ft of water* H	M	L	P-P	Predominant Frequency Hz
6A	951.6	0.7	A	50.6	50.5	50.4	0.2	2
			B	33.1	33.0	32.9	0.2	1
			C	1.7	0.9	0.4	1.4	7
			D	4.0	3.5	3.3	0.5	2
6B	951.6	3.8	A	39.5	39.2	39.1	0.4	2
			B	14.2	14.1	13.8	0.4	10
			C	0.2	-0.7	-1.4	1.3	10
			D	3.9	3.2	2.4	1.2	2
6C	951.6	8.1	A	26.3	26.1	25.9	0.3	2
			B	13.0	12.7	12.5	0.4	30
			C	-1.1	-1.8	-2.5	1.3	2
			D	1.4	0.3	-0.3	1.5	10
6E	951.6	15.6	A	17.6	17.4	17.0	0.5	2
			B	11.1	10.9	10.5	0.6	2
			C	-1.2	-2.1	-2.7	1.4	13
			D	0.0	-1.4	-2.0	1.8	10
6H	951.6	34.0	A	2.0	1.2	0.8	1.0	6
			B	3.3	2.6	2.0	1.3	10
			C	-0.8	-1.8	-2.6	1.8	10
			D	0.2	-0.9	-1.5	1.6	16

* H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P-P = greatest instantaneous peak-to-peak pressure fluctuation.

Table 14

Trunnion Bridge Vibration

Adjacent Gate Closed

Test 1

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
1A	0.7	Vertical	0.005	-0.002	0.007	72	1.10
		Longitudinal	0.003	-0.003	0.006	72	0.94
		Transverse	0.002	-0.005	0.007	72	1.10
1B	3.8	Vertical	0.005	-0.002	0.002	124	0.37
		Longitudinal	0.003	-0.003	0.006	182	0.15
		Transverse	0.001	-0.004	0.005	36	3.15
1C	8.1	Vertical	0.005	-0.002	0.007	262	0.08
		Longitudinal	0.003	-0.004	0.007	280	0.07
		Transverse	0.003	-0.004	0.007	10	57.09
1E	15.6	Vertical	0.013	-0.004	0.017	224	0.28
		Longitudinal	0.004	-0.010	0.014	288	0.14
		Transverse	0.003	-0.004	0.003	10	57.09
1H	34.0	Vertical	0.006	-0.005	0.011	116	0.61
		Longitudinal	0.012	-0.002	0.014	96	1.24
		Transverse	0.008	-0.010	0.018	12	101.90

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 15

Trunnion Bridge Vibration

Adjacent Gate Full Open

Test 2

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
2A	0.7	Vertical	0.002	-0.007	0.009	55	2.42
		Longitudinal	0.001	-0.007	0.008	88	0.84
		Transverse	0.005	-0.005	0.010	12	56.64
2B	3.8	Vertical	0.002	-0.007	0.009	55	2.43
		Longitudinal	0.006	-0.004	0.010	75	1.45
		Transverse	0.005	-0.006	0.011	11	74.15
2C	8.1	Vertical	0.004	-0.011	0.015	224	0.16
		Longitudinal	0.005	-0.005	0.010	96	0.88
		Transverse	0.006	-0.006	0.012	10	97.87
2E	15.6	Vertical	0.004	-0.011	0.015	94	1.38
		Longitudinal	0.009	-0.009	0.018	72	2.83
		Transverse	0.007	-0.008	0.015	11	101.11

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 16

Trunnion Bridge Vibration

Adjacent Gate at Same Opening

Test 3

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
3A	0.7	Vertical	0.002	-0.004	0.006	72	0.94
		Longitudinal	0.002	-0.003	0.005	112	0.32
		Transverse	0.002	-0.003	0.005	116	0.30
3B	3.8	Vertical	0.003	-0.004	0.007	140	0.29
		Longitudinal	0.003	-0.003	0.006	142	0.24
		Transverse	0.002	-0.003	0.005	12	28.32
3C	8.1	Vertical	0.004	-0.007	0.011	192	0.24
		Longitudinal	0.004	-0.008	0.012	194	0.26
		Transverse	0.003	-0.004	0.007	25	9.13
3E	15.6	Vertical	0.008	-0.013	0.021	280	0.22
		Longitudinal	0.006	-0.011	0.017	284	0.17
		Transverse	0.005	-0.005	0.010	9	100.69
3H	34.0	Vertical	0.002	-0.009	0.010	252	0.13
		Longitudinal	0.002	-0.010	0.012	88	1.26
		Transverse	0.007	-0.008	0.015	12	84.96

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 17

Trunnion Bridge Vibration

Adjacent Gate Closed

Test 4

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
4A	0.7	Vertical	0.016	-0.012	0.028	138	1.20
		Longitudinal	0.014	-0.022	0.036	138	1.54
		Transverse	0.002	-0.026	0.028	53	8.71
4B	3.8	Vertical	0.010	-0.035	0.045	312	0.38
		Longitudinal	0.020	-0.022	0.044	75	6.09
		Transverse	0.020	-0.017	0.037	9	372.57
4C	8.1	Vertical	0.038	-0.070	0.108	320	0.86
		Longitudinal	0.020	-0.110	0.130	286	1.30
		Transverse	0.005	-0.020	0.025	22	42.13
4E	15.6	Vertical	0.100	-0.076	0.176	312	1.47
		Longitudinal	0.062	-0.090	0.152	284	1.53
		Transverse	0.025	-0.029	0.054	9	543.75
4H	34.0	Vertical	0.040	-0.052	0.092	53	26.71
		Longitudinal	0.056	-0.066	0.122	75	17.69
		Transverse	0.034	-0.056	0.090	12	509.77

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 18

Trunnion Bridge Vibration

Adjacent Gate Full Open

Test 5

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
5A	0.7	Vertical	0.031	-0.033	0.064	55	17.26
		Longitudinal	0.034	-0.036	0.070	75	10.15
		Transverse	0.048	-0.042	0.090	55	24.27
5B	3.8	Vertical	0.032	-0.035	0.067	55	18.06
		Longitudinal	0.037	-0.032	0.069	75	10.00
		Transverse	0.056	-0.042	0.098	11	660.80
5C	8.1	Vertical	0.034	-0.036	0.070	106	5.08
		Longitudinal	0.034	-0.068	0.112	97	6.41
		Transverse	0.042	-0.052	0.094	10	766.69
5E	15.6	Vertical	0.050	-0.056	0.106	94	9.78
		Longitudinal	0.044	-0.068	0.112	75	16.24
		Transverse	0.064	-0.072	0.136	11	916.75

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 19

Trunnion Bridge Vibration

Adjacent Gate at Same Opening

Test 6

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
6A	0.7	Vertical	0.017	-0.010	0.027	138	1.16
		Longitudinal	0.017	-0.016	0.033	75	4.78
		Transverse	0.016	-0.014	0.030	53	8.71
6B	3.8	Vertical	0.021	-0.016	0.037	312	0.31
		Longitudinal	0.015	-0.021	0.036	75	5.22
		Transverse	0.017	-0.018	0.035	10	285.47
6C	8.1	Vertical	0.042	-0.042	0.084	286	0.84
		Longitudinal	0.052	-0.064	0.116	284	1.17
		Transverse	0.024	-0.022	0.046	22	77.52
6E	15.6	Vertical	0.045	-0.046	0.091	312	0.76
		Longitudinal	0.040	-0.042	0.082	340	0.58
		Transverse	0.036	-0.028	0.064	9	644.45
6H	34.0	Vertical	0.058	-0.042	0.100	15	362.50
		Longitudinal	0.064	-0.060	0.124	75	17.98
		Transverse	0.072	-0.080	0.152	12	860.94

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 20

Access Gallery Vibration

Adjacent Gate Closed

Test 1

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
1A	0.7	Vertical	0.012	-0.020	0.032	72	5.04
		Longitudinal	0.024	-0.024	0.048	120	2.72
		Transverse	0.005	-0.035	0.040	178	1.03
1B	3.8	Vertical	0.001	-0.002	0.003	58	0.73
		Longitudinal	0.028	-0.028	0.056	118	3.28
		Transverse	0.015	-0.017	0.032	178	0.82
1C	8.1	Vertical	0.016	-0.015	0.031	178	0.79
		Longitudinal	0.010	-0.050	0.060	118	3.51
		Transverse	0.017	-0.017	0.034	118	2.16
1E	15.6	Vertical	0.024	-0.028	0.052	293	0.49
		Longitudinal	0.001	-0.070	0.071	220	1.20
		Transverse	0.020	-0.017	0.037	118	2.16
1H	34.0	Vertical	0.010	-0.010	0.020	46	7.71
		Longitudinal	0.010	-0.070	0.080	172	2.20
		Transverse	0.008	-0.032	0.040	118	2.34

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 21

Access Gallery Vibration

Adjacent Gate Full Open

Test 2

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
2A	0.7	Vertical	0.013	-0.013	0.026	72	4.09
		Longitudinal	0.018	-0.018	0.036	118	2.11
		Transverse	0.010	-0.011	0.021	178	0.54
2B	3.8	Vertical	0.016	-0.009	0.025	50	8.16
		Longitudinal	0.020	-0.017	0.037	118	2.17
		Transverse	0.011	-0.011	0.022	154	0.76
2C	8.1	Vertical	0.014	-0.008	0.022	76	3.11
		Longitudinal	0.017	-0.023	0.040	118	2.34
		Transverse	0.016	-0.008	0.024	172	0.66
2E	15.6	Vertical	0.020	-0.005	0.025	96	2.21
		Longitudinal	0.020	-0.022	0.040	118	5.15
		Transverse	0.016	-0.010	0.026	180	0.65

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 22

Access Gallery Vibration

Adjacent Gate at Same Opening

Test 3

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
3A	0.7	Vertical	0.012	-0.008	0.020	172	0.51
		Longitudinal	0.018	-0.015	0.033	120	1.87
		Transverse	0.008	-0.014	0.022	172	0.56
3B	3.8	Vertical	0.008	-0.014	0.022	172	0.56
		Longitudinal	0.017	-0.017	0.034	118	1.99
		Transverse	0.007	-0.015	0.022	176	0.58
3C	8.1	Vertical	0.016	-0.008	0.024	178	0.62
		Longitudinal	0.020	-0.018	0.038	118	2.22
		Transverse	0.010	-0.013	0.023	178	0.60
3E	15.6	Vertical	0.024	-0.010	0.034	292	0.32
		Longitudinal	0.026	-0.024	0.050	118	2.92
		Transverse	0.012	-0.015	0.027	264	0.32
3H	34.0	Vertical	0.018	-0.012	0.030	72	4.72
		Longitudinal	0.026	-0.020	0.046	118	2.69
		Transverse	0.020	-0.011	0.031	110	2.09

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 23

Access Gallery Vibration

Adjacent Gate Closed

Test 4

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
4A	0.7	Vertical	0.004	-0.028	0.032	193	0.70
		Longitudinal	0.015	-0.035	0.050	118	2.93
		Transverse	0.016	-0.017	0.033	178	0.85
4B	3.8	Vertical	0.024	-0.006	0.050	178	2.45
		Longitudinal	0.016	-0.035	0.051	120	2.89
		Transverse	0.020	-0.012	0.034	178	0.88
4C	8.1	Vertical	0.032	-0.008	0.040	178	1.03
		Longitudinal	0.010	-0.050	0.060	118	3.51
		Transverse	0.022	-0.012	0.034	118	1.99
4E	15.6	Vertical	0.029	-0.029	0.058	293	0.55
		Longitudinal	0.029	-0.023	0.052	216	0.91
		Transverse	0.032	-0.029	0.061	118	3.53
4H	34.0	Vertical	0.020	-0.020	0.040	46	15.42
		Longitudinal	0.026	-0.024	0.050	178	1.28
		Transverse	0.029	-0.025	0.054	118	3.16

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 24

Access Gallery Vibration

Adjacent Gate Full Open

Test 5

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
5A	0.7	Vertical	0.019	-0.016	0.035	78	4.69
		Longitudinal	0.028	-0.026	0.054	118	3.16
		Transverse	0.016	-0.017	0.033	178	0.85
5B	3.8	Vertical	0.017	-0.018	0.035	50	11.42
		Longitudinal	0.025	-0.025	0.050	118	2.93
		Transverse	0.018	-0.016	0.034	178	0.78
5C	8.1	Vertical	0.018	-0.020	0.038	76	5.37
		Longitudinal	0.031	-0.024	0.055	118	3.22
		Transverse	0.019	-0.020	0.039	178	1.00
5E	15.6	Vertical	0.023	-0.022	0.045	50	14.68
		Longitudinal	0.024	-0.020	0.054	120	3.06
		Transverse	0.018	-0.028	0.046	180	1.16

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

Table 25

Access Gallery Vibration

Adjacent Gate at Same Opening

Test 6

Test No.	Gate Opening ft	Transducer Orientation*	Acceleration, g's** Max	Min	P-P	Predominant Frequency Hz	Displacement μft†
6A	0.7	Vertical	0.016	-0.020	0.036	178	0.93
		Longitudinal	0.029	-0.025	0.054	118	3.16
		Transverse	0.016	-0.020	0.036	178	0.93
6B	3.8	Vertical	0.015	-0.016	0.031	180	0.78
		Longitudinal	0.026	-0.026	0.052	120	2.94
		Transverse	0.016	-0.015	0.031	178	0.79
6C	8.1	Vertical	0.018	-0.015	0.033	300	0.30
		Longitudinal	0.033	-0.030	0.063	120	3.57
		Transverse	0.015	-0.017	0.032	179	0.84
6E	15.6	Vertical	0.020	-0.017	0.037	178	0.95
		Longitudinal	0.027	-0.024	0.031	118	2.99
		Transverse	0.016	-0.017	0.033	178	0.85
6H	34.0	Vertical	0.020	-0.020	0.040	50	13.05
		Longitudinal	0.032	-0.030	0.062	120	3.39
		Transverse	0.020	-0.018	0.038	55	10.25

* Vertical = up and down direction; Longitudinal = upstream and downstream direction; and Transverse = direction perpendicular to flow.

** Max = greatest instantaneous acceleration in the positive direction (+); Min = greatest instantaneous acceleration in the negative direction (-); P-P = greatest peak-peak acceleration.

† μft = 0.000001 ft.

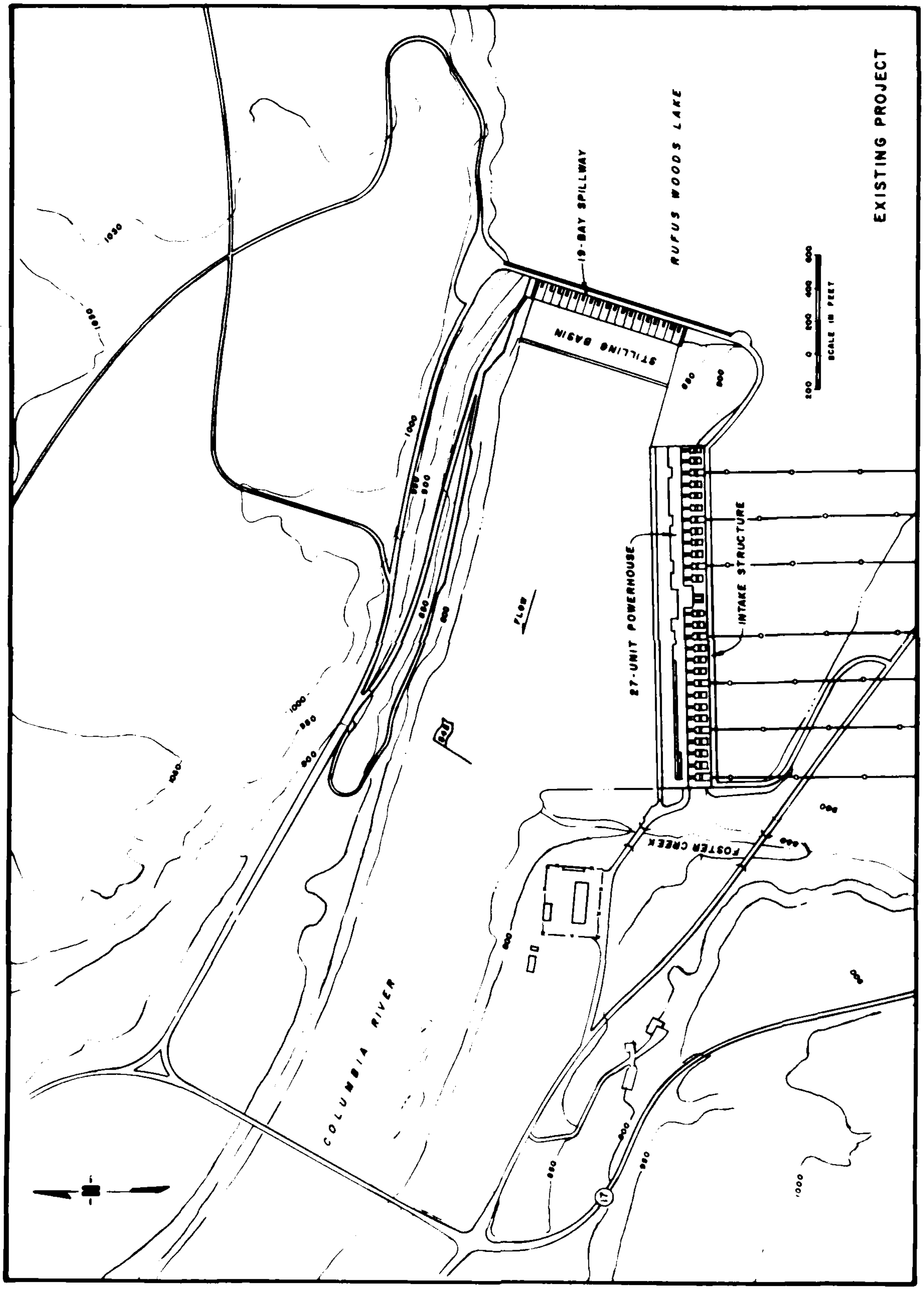
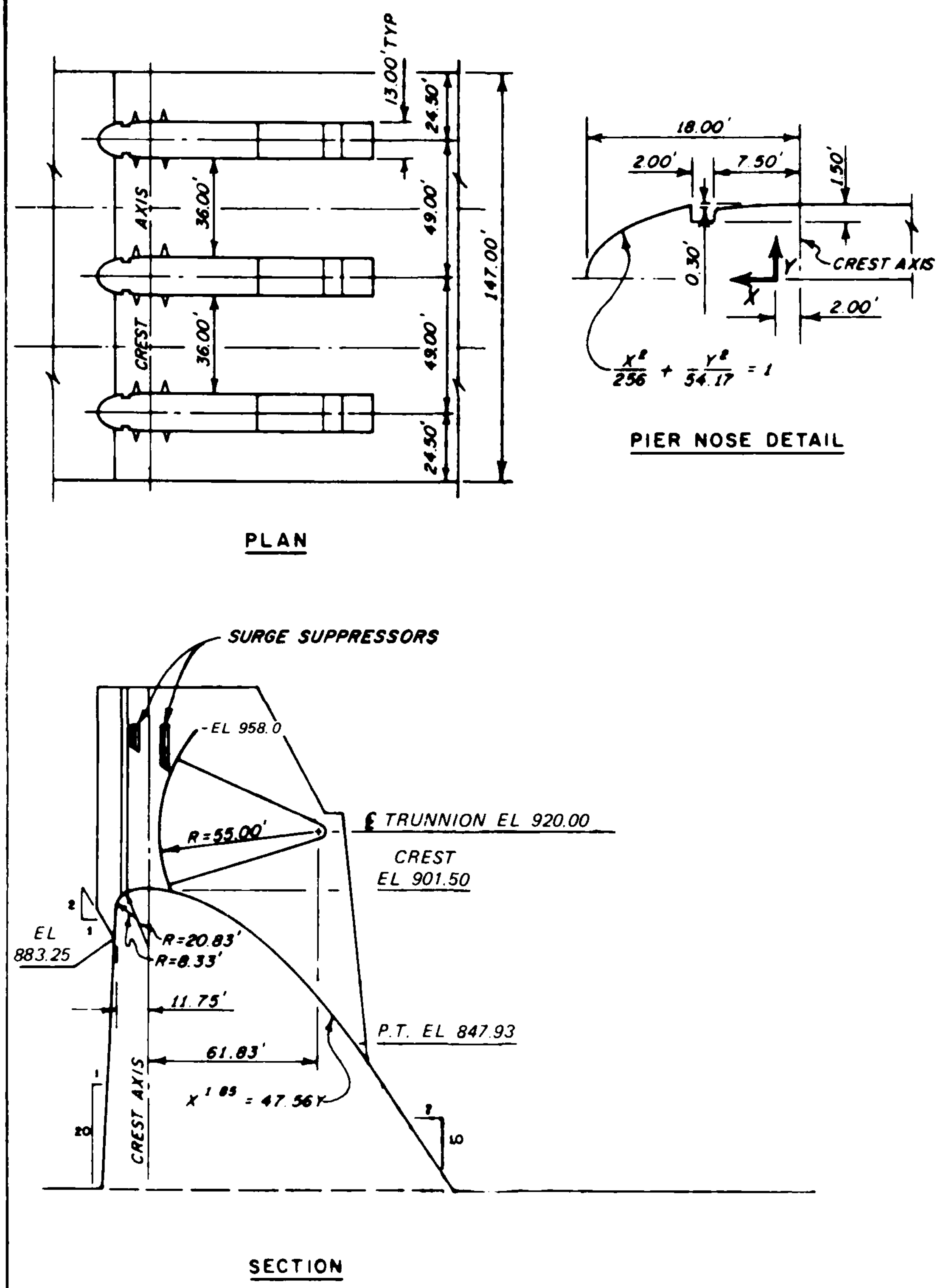
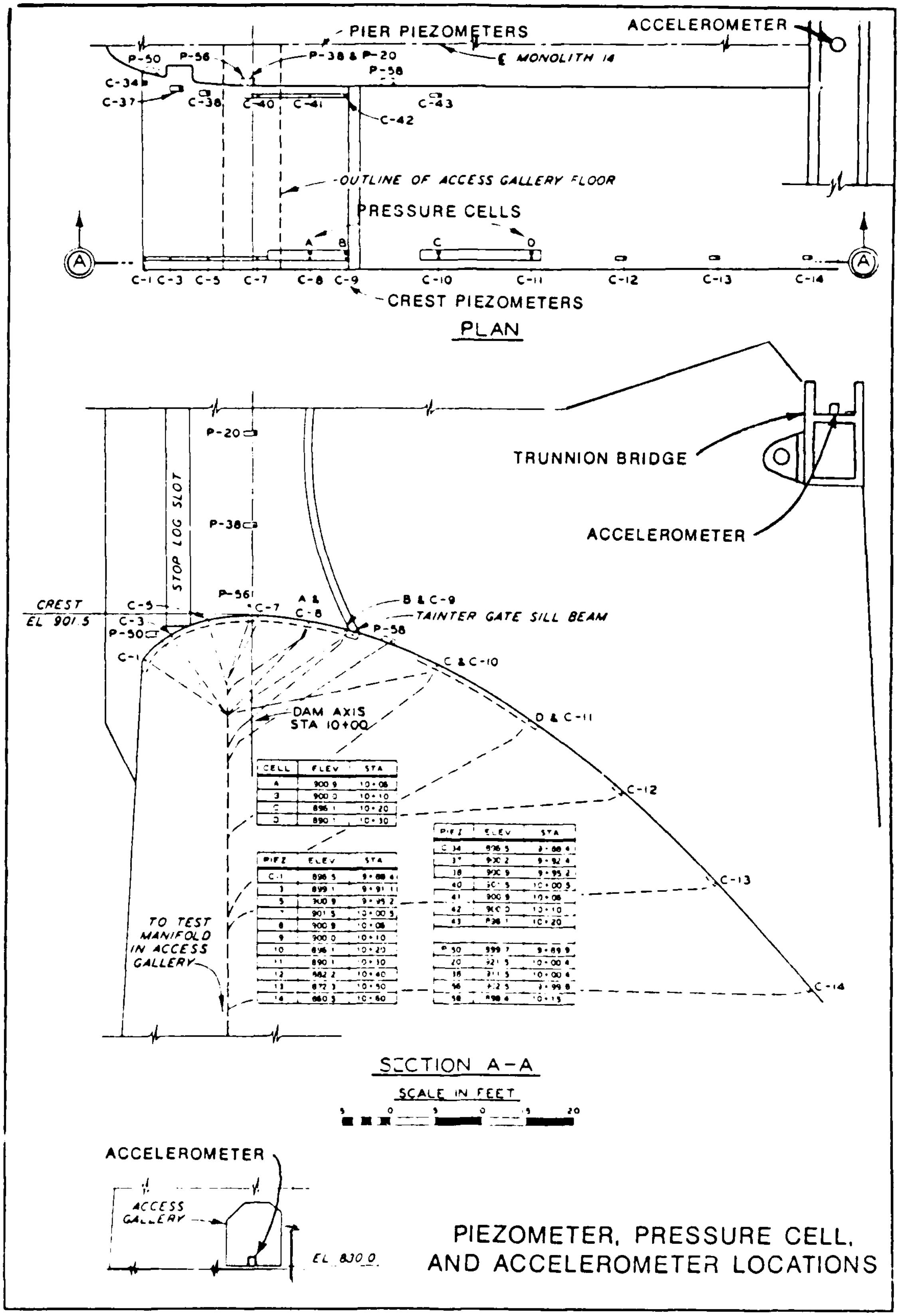

EXISTING PROJECT
RUFUS WOODS LAKE
19-BAY SPILLWAY
STILLING BASIN
27-UNIT POWERHOUSE
INTAKE STRUCTURE
FLOW
COLUMBIA RIVER
FOSTER CREEK
200 0 200 400 600
SCALE IN FEET

PLATE 1



DETAIL OF SPILLWAY BAYS

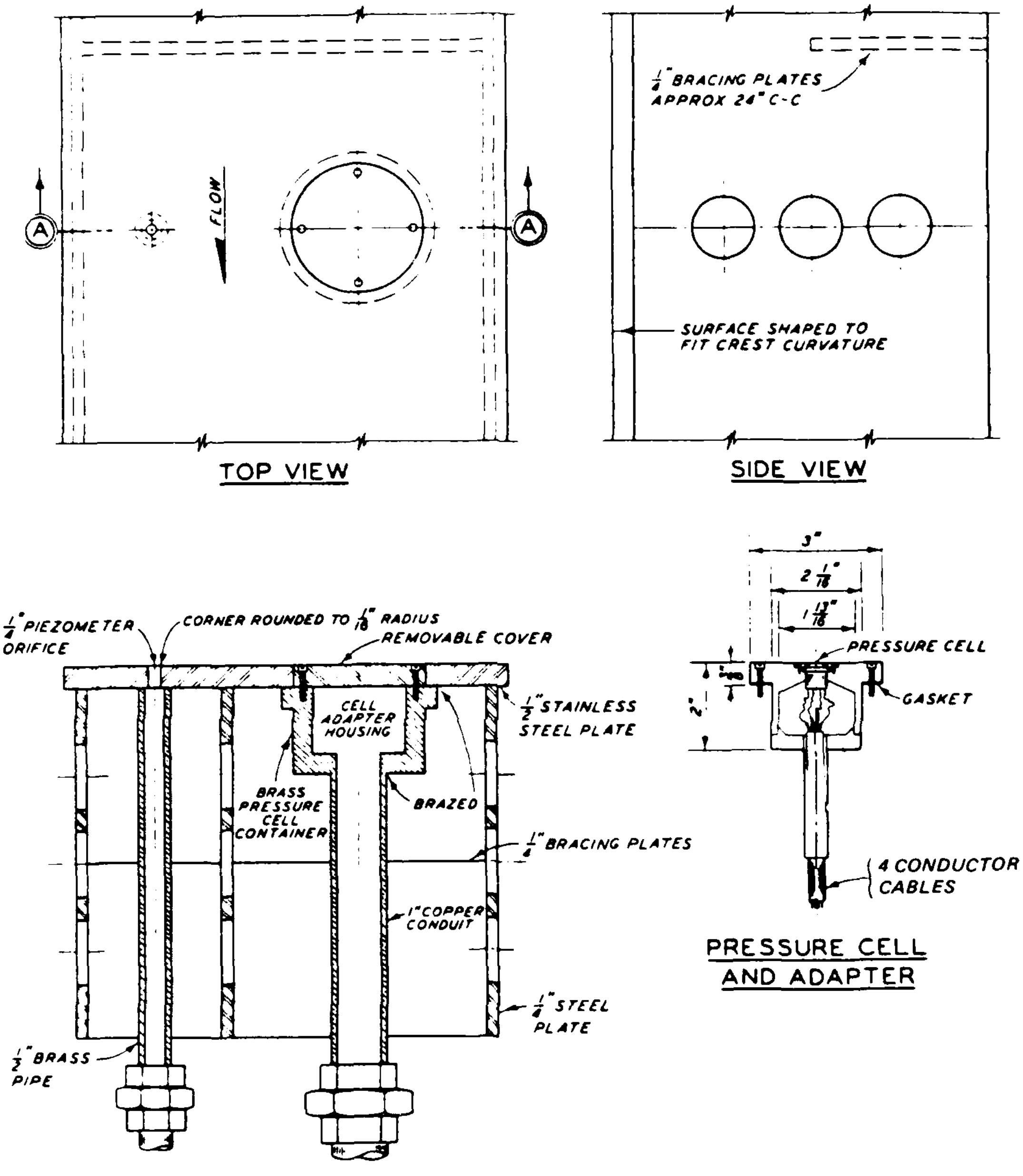


CELL	ELEV	STA
A	900.9	10+08
B	900.0	10+10
C	896.1	10+20
D	890.1	10+30

PIEZ	ELEV	STA
C-1	896.5	9+88.4
3	899.1	9+91.1
5	900.9	9+95.2
7	901.5	10+00.5
8	900.9	10+08
9	900.0	10+10
10	896.1	10+20
11	890.1	10+30
12	882.2	10+40
13	872.3	10+50
14	860.3	10+60

PIEZ	ELEV	STA
C-34	[illegible]	9+88.4
37	900.2	9+92.4
38	900.9	9+95.2
40	[illegible]	10+00.5
41	900.9	10+08
42	900.0	10+10
43	[illegible]	10+20
P-50	[illegible]	9+89.9
20	921.5	10+00.4
38	[illegible]	10+00.4
56	[illegible]	9+99.8
58	[illegible]	10+15

PIEZOMETER, PRESSURE CELL, AND ACCELEROMETER LOCATIONS

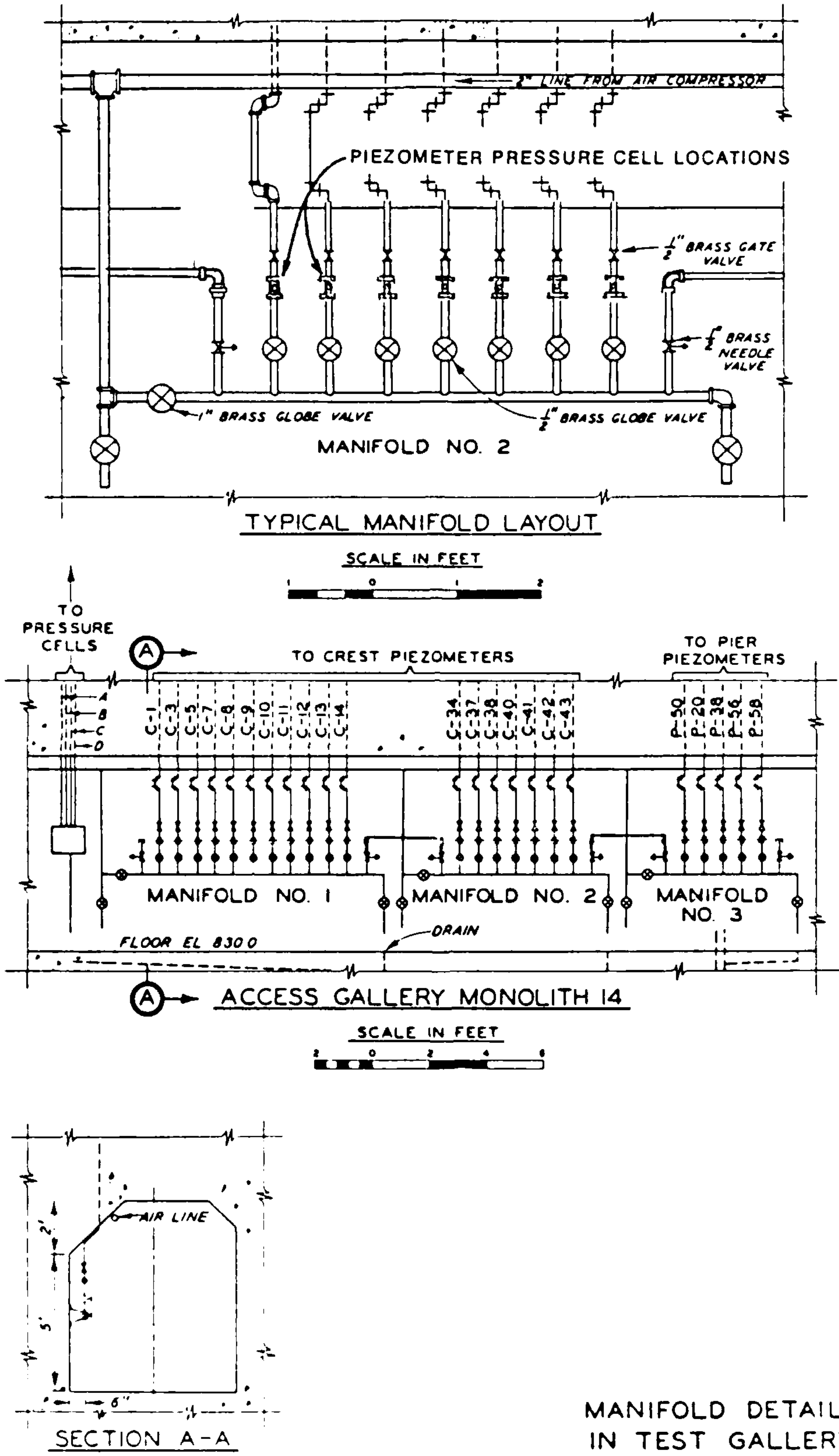


DETAILS OF PIEZOMETER AND PRESSURE CELL PLATES

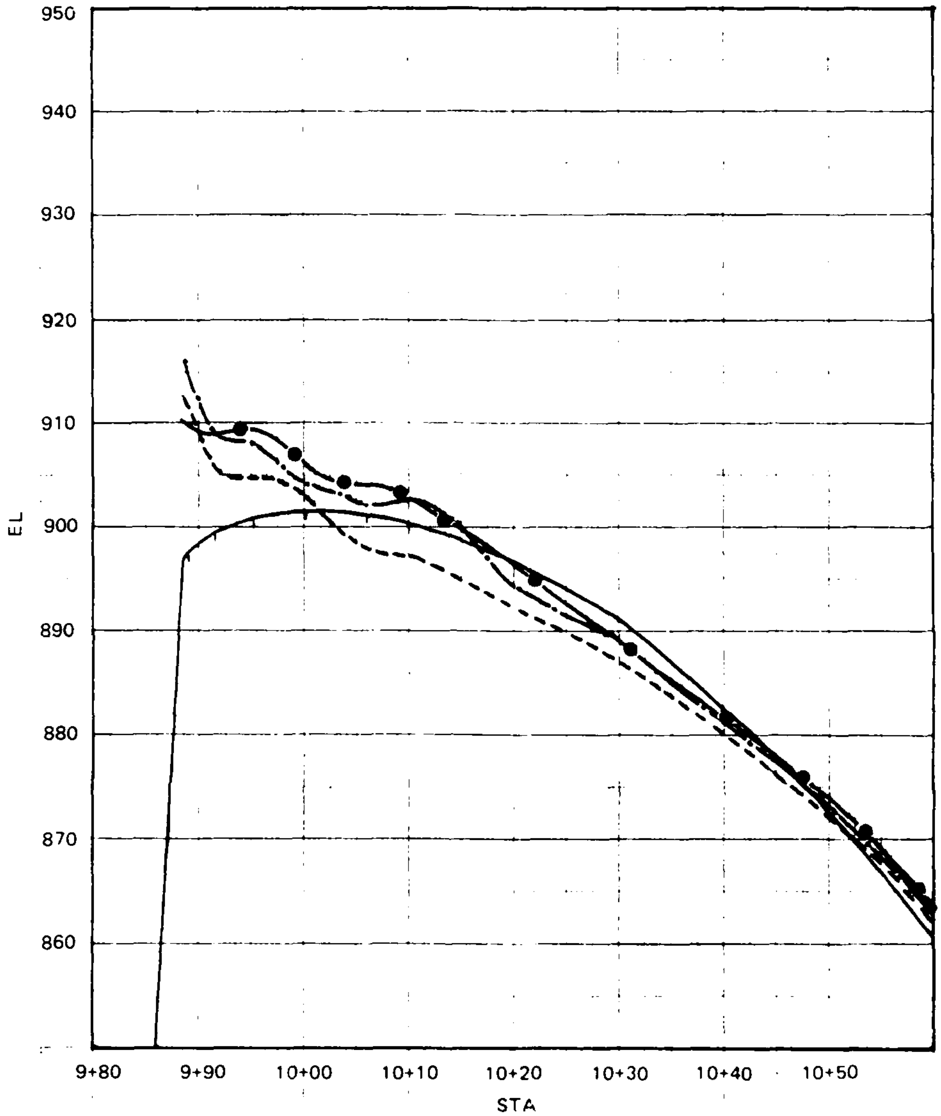
SCALE IN INCHES

1 0 1 2 3 4 5

PLATE 4



MANIFOLD DETAILS
IN TEST GALLERY



CENTER LINE, BAY 9

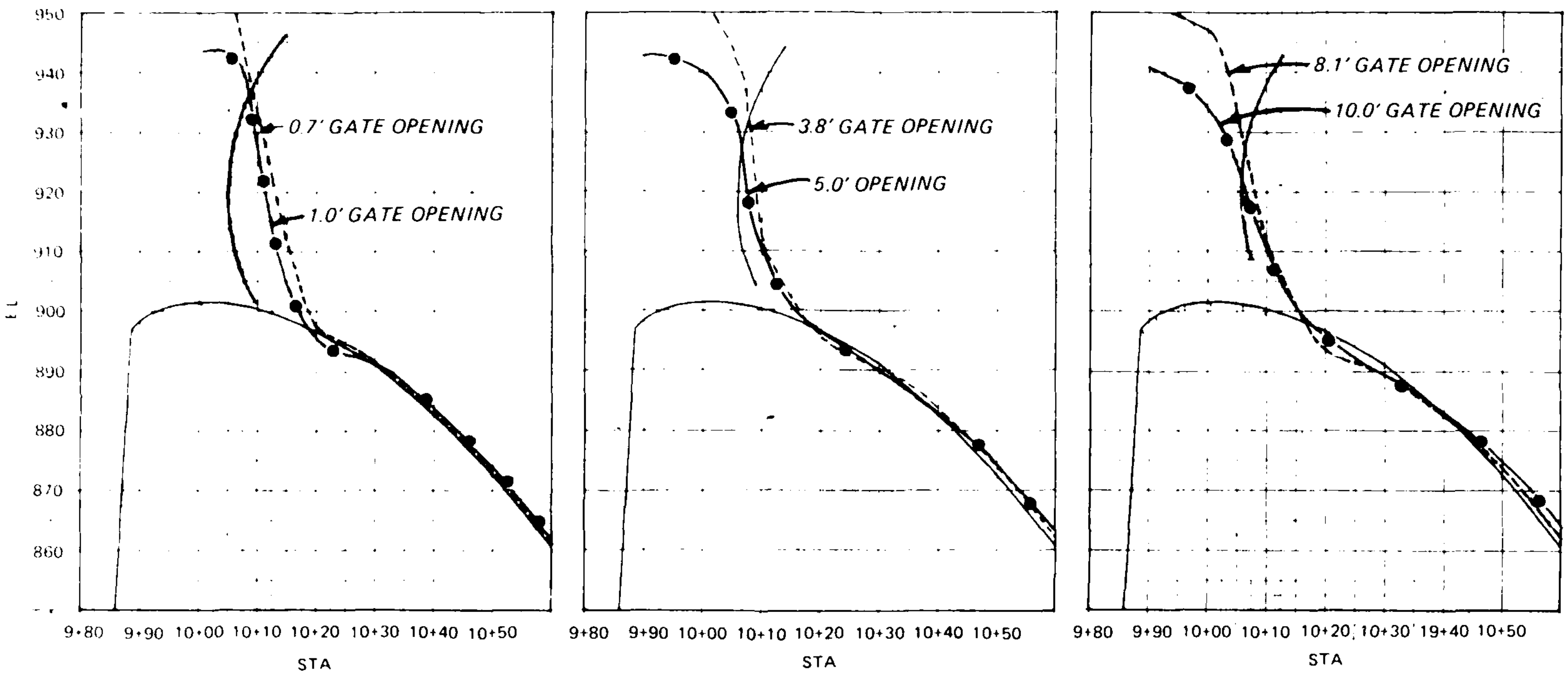
LEGEND

- - - - - PROTOTYPE DATA; 1.31 H_d

-·——·- PROTOTYPE DATA; 1.21 H_d

-●—●- PROTOTYPE DATA; 1.10 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE FULL OPEN
FREE OVERFLOW
1.31 H_d, 1.21 H_d, AND 1.1 H_d



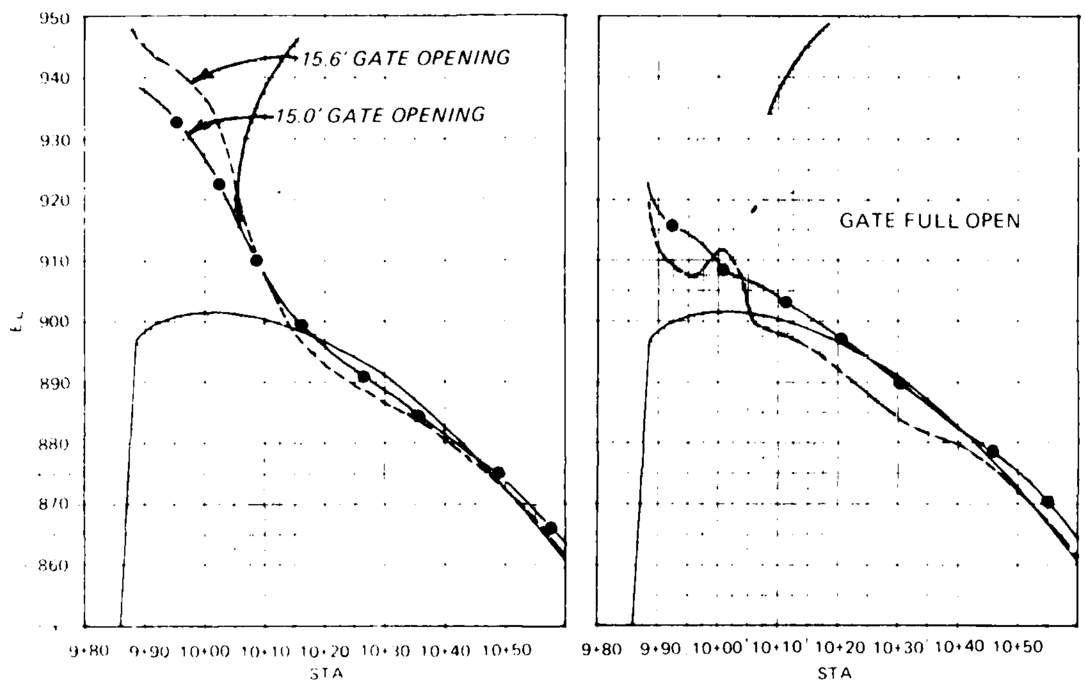
CENTER LINE OF BAY 9

LEGEND

- - - - - - PROTOTYPE DATA, 1.31 H_d (1985)

-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE CLOSED
1.31 H_d AND 1.0 H_d
GATE 9 OPEN: 0.7 — 10.0 FT

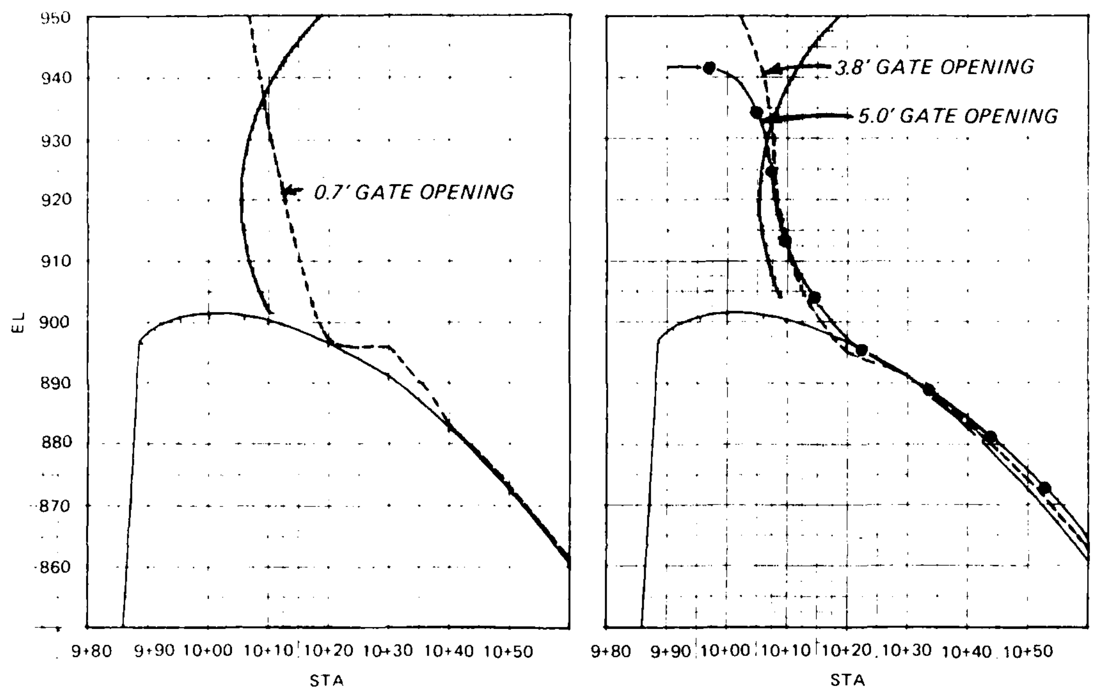


CENTER LINE OF BAY 9

LEGEND

- - - - - PROTOTYPE DATA 1.31 H_d (1985)
-●—●- PROTOTYPE DATA 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE CLOSED
1.31 H_d AND 1.0 H_d
GATE 9 OPEN: 15.0 FT FULL OPEN



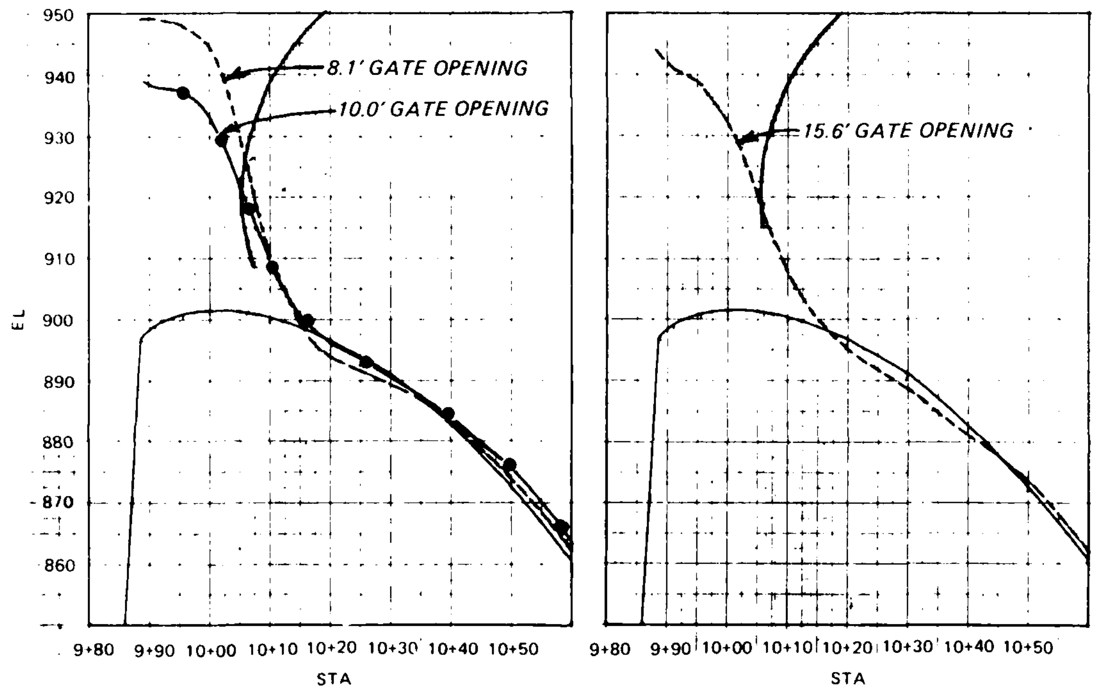
CENTER LINE OF BAY 9

LEGEND

- - - - - PROTOTYPE DATA, 1.31 H_d (1985)

-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE FULL OPEN
1.31 H_d AND 1.0 H_d
GATE 9 OPEN: 0.7 - 5.0 FT

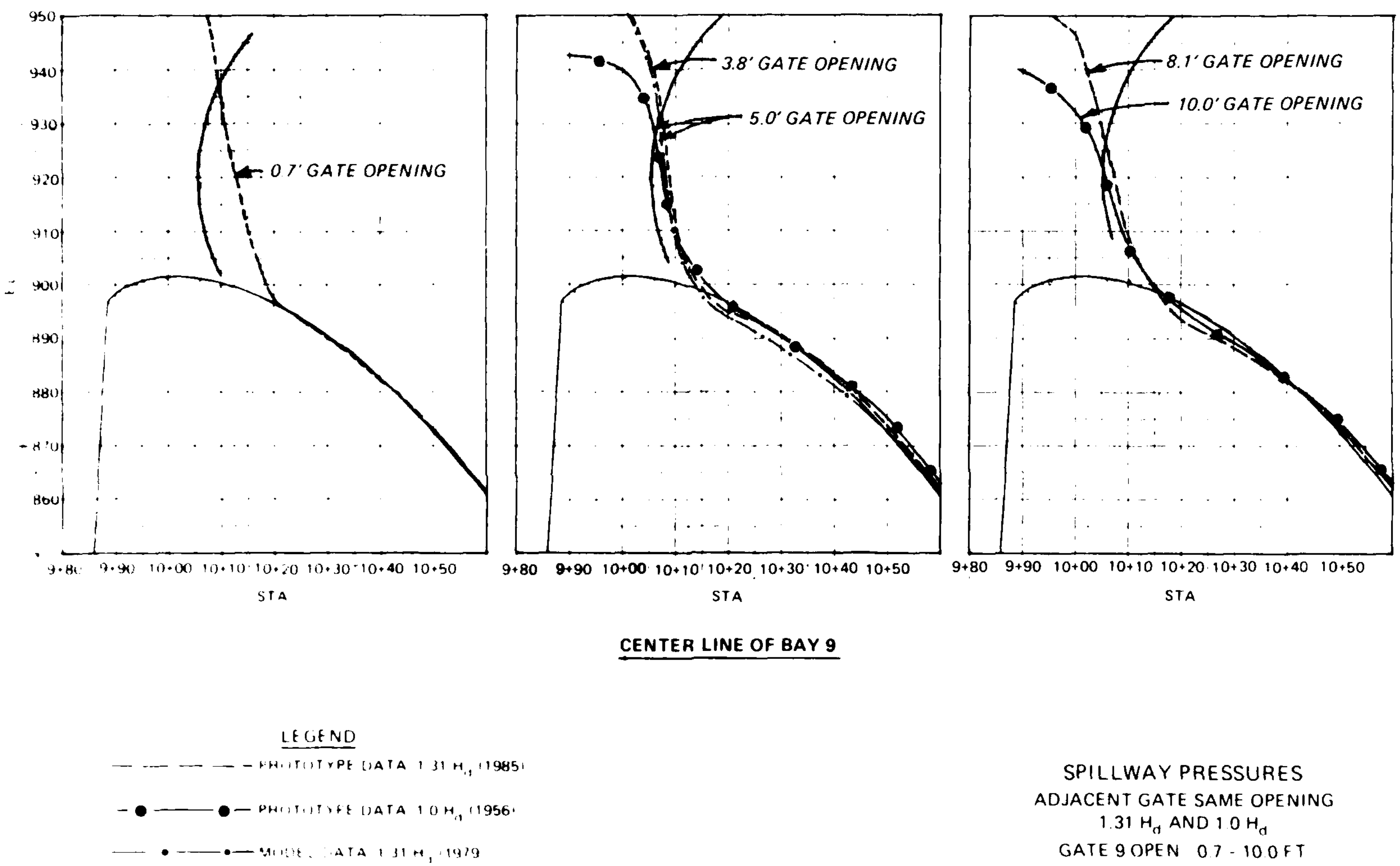


CENTER LINE OF BAY 9

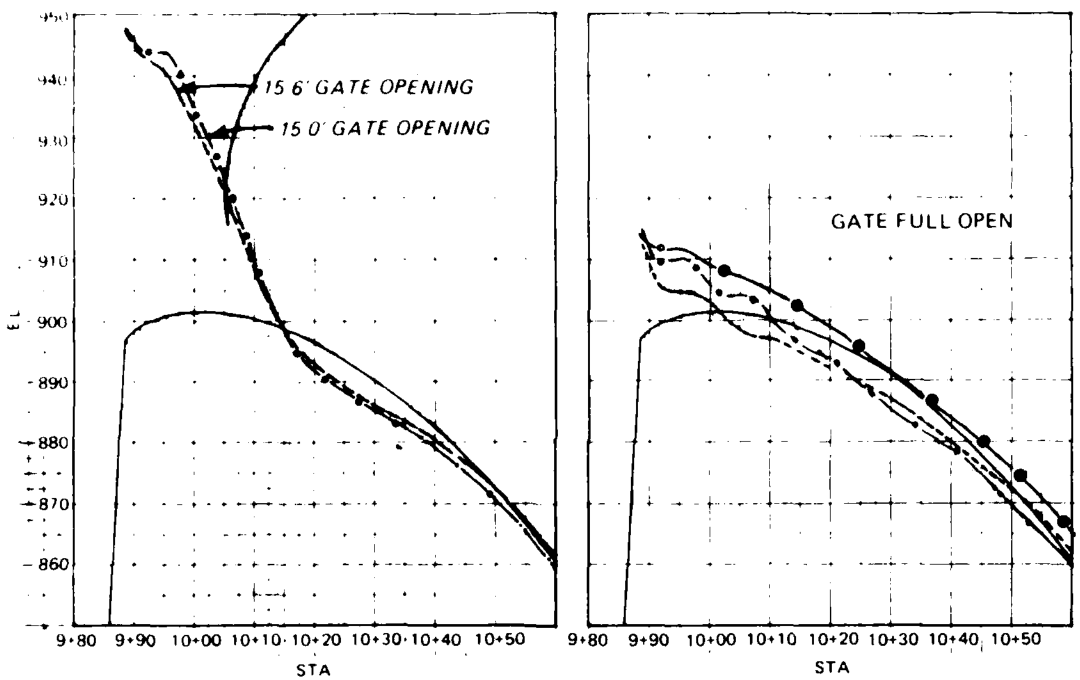
LEGEND

- - - - PROTOTYPE DATA, 1.31 H_d (1985)
-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE FULL OPEN
1.31 H_d AND 1.0 H_d
GATE 9 OPEN: 8.1 - 15.6 FT



SPILLWAY PRESSURES
ADJACENT GATE SAME OPENING
1.31 H_d AND 1.0 H_d
GATE 9 OPEN 0.7 - 10.0 FT

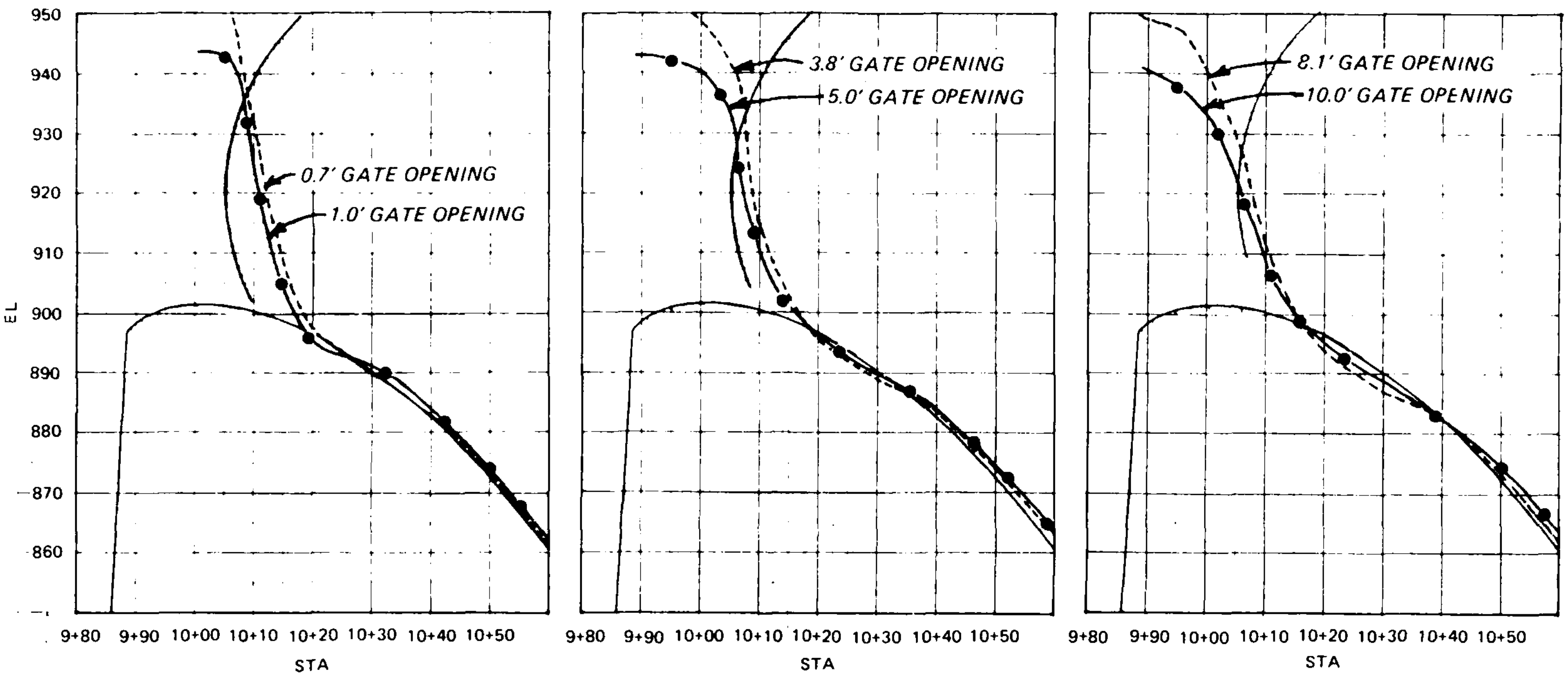


CENTER LINE OF BAY 9

LEGEND

- PROTOTYPE DATA, 1.31 H_d (1985)
- PROTOTYPE DATA, 1.0 H_d (1956)
- MODEL DATA 1.31 H_d (1979)

SPILLWAY PRESSURES
ADJACENT GATE SAME OPENING
1.31 H_d AND 1.0 H_d
GATE 9 OPEN: 15.0 FT - FULL OPEN

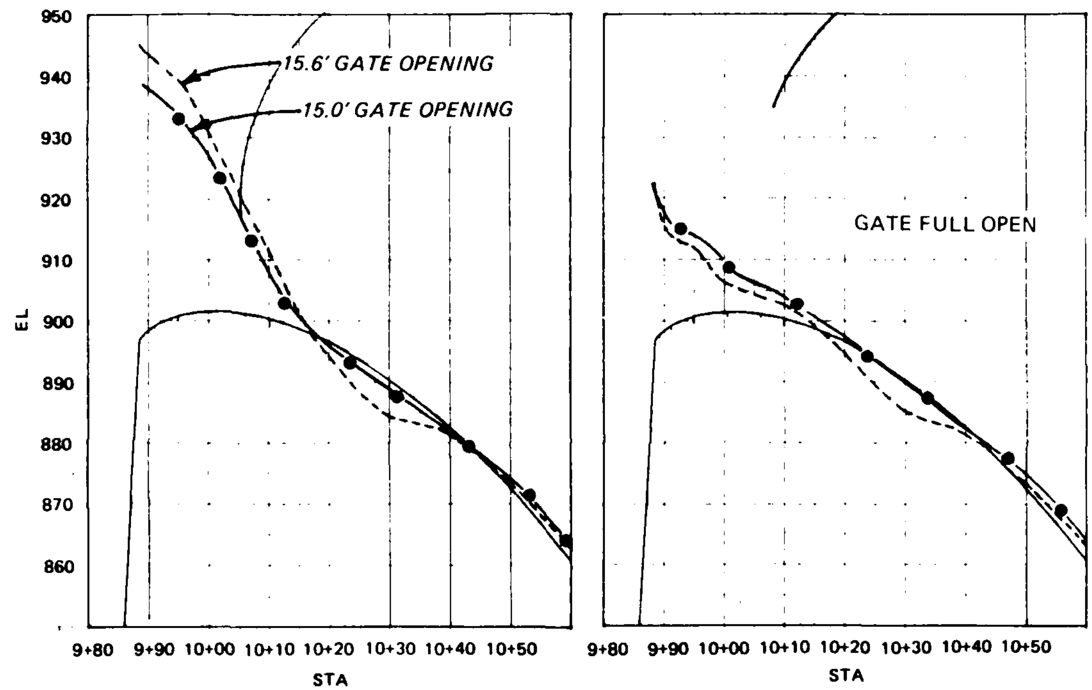


CENTER LINE OF BAY 9

LEGEND

- - - - - PROTOTYPE DATA, 1.21 H_d (1985)
-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE CLOSED
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 0.7 - 10.0 FT



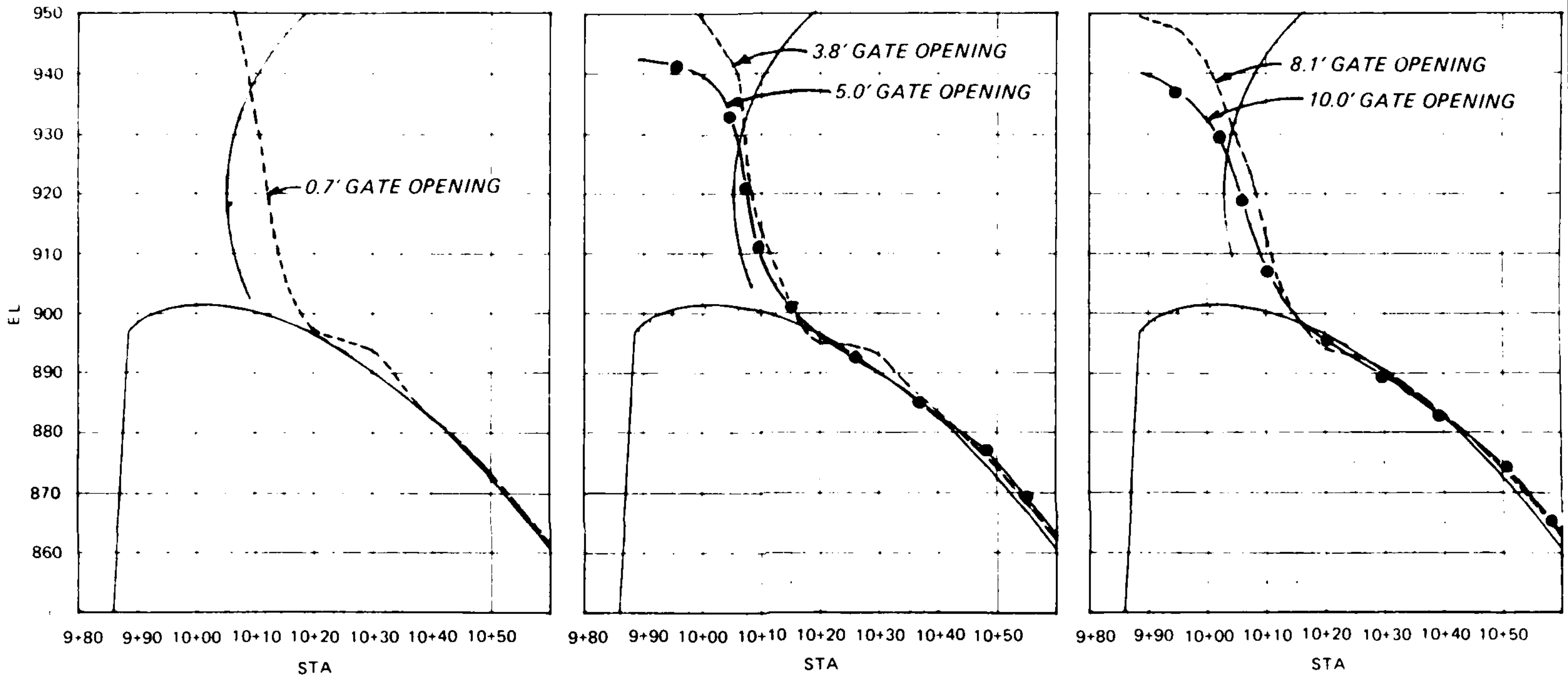
CENTER LINE OF BAY 9

LEGEND

- - - - PROTOTYPE DATA, 1.21 H_d (1985)

-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE CLOSED
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 15.0 FT - FULL OPEN



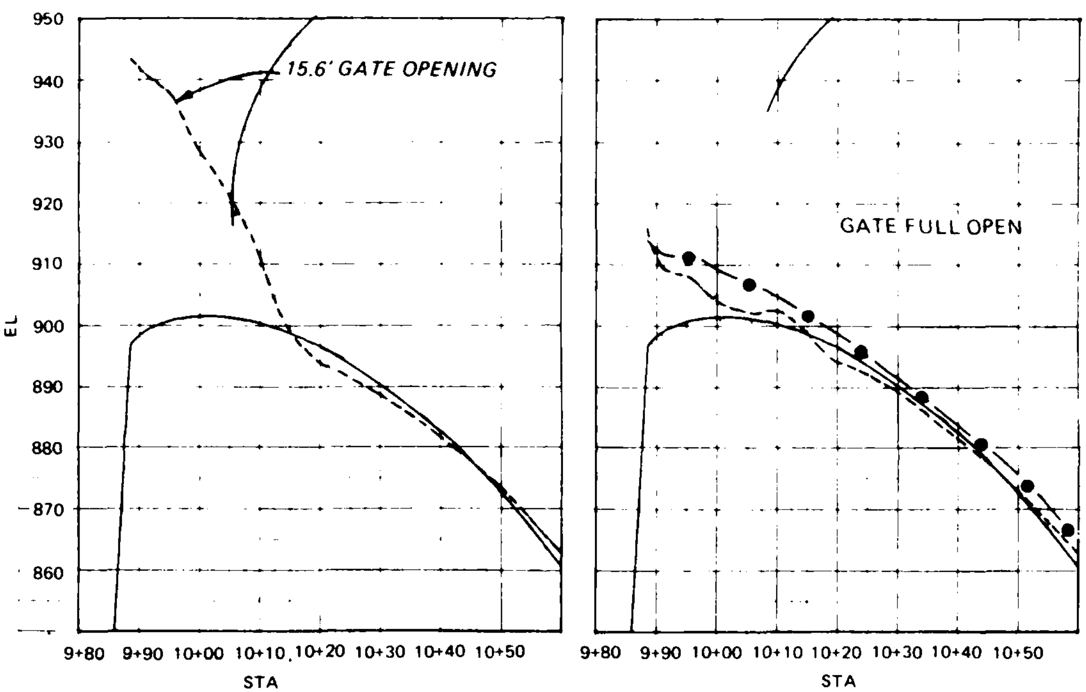
CENTER LINE OF BAY 9

LEGEND

- - - - - PROTOTYPE DATA, 1.21 H_d (1985)

-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE SAME OPENING
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 0.7 - 10.0 FT



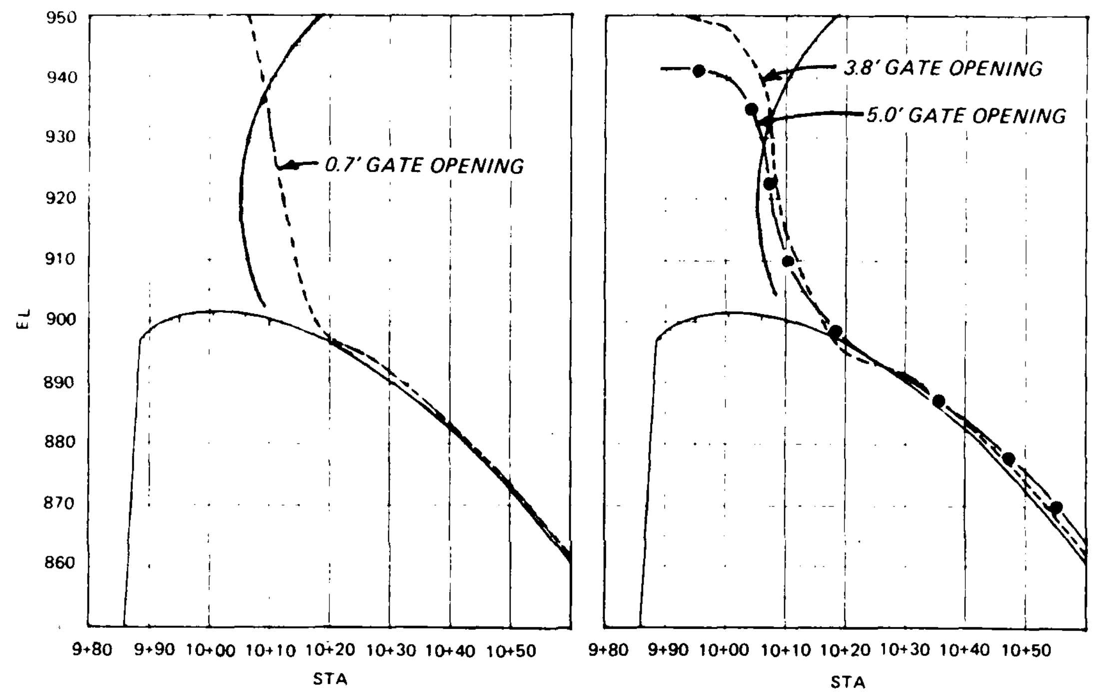
CENTER LINE OF BAY 9

LEGEND

PROTOTYPE DATA, 1.21 H_d (1985)

PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE SAME OPENING
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 15.6 FT - FULL OPEN



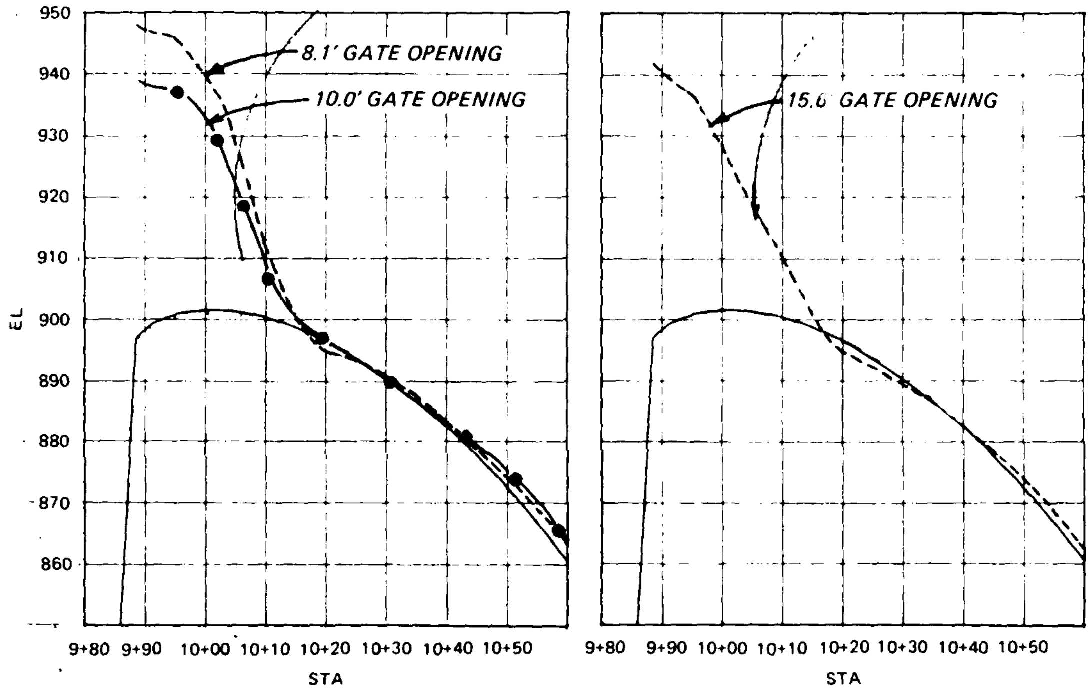
CENTER LINE OF BAY 9

LEGEND

PROTOTYPE DATA, 1.21 H_d (1985)

PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE FULL OPEN
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 0.7 - 5.0 FT

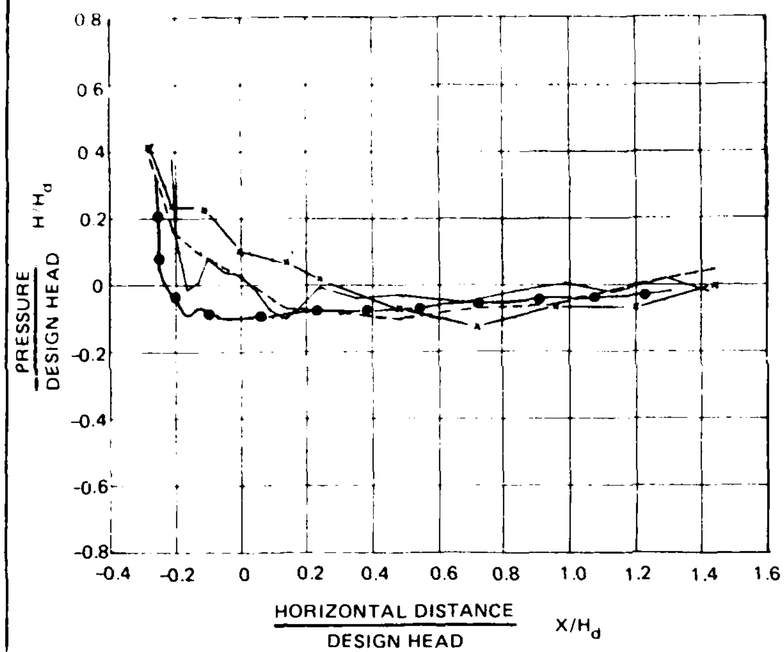


CENTER LINE OF BAY 9

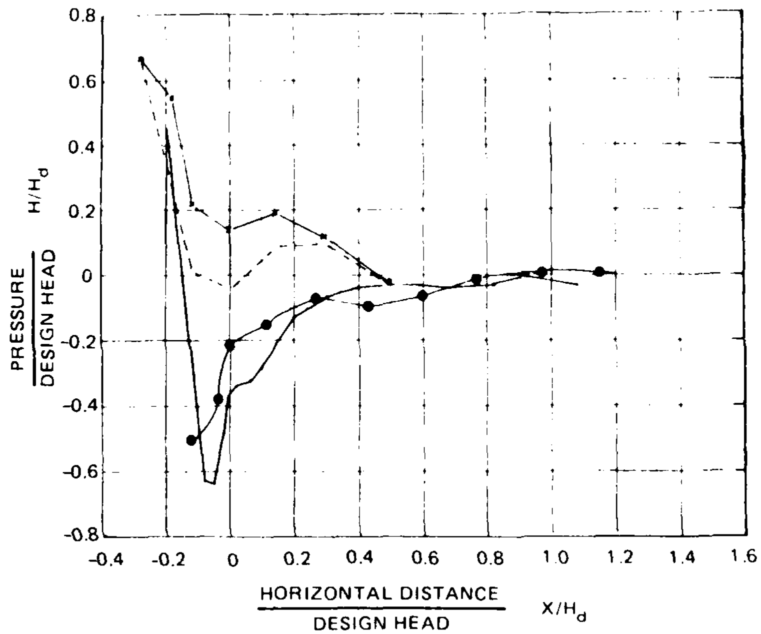
LEGEND

- - - - - PROTOTYPE DATA; 1.21 H_d (1985)
-●—●- PROTOTYPE DATA, 1.0 H_d (1956)

SPILLWAY PRESSURES
ADJACENT GATE GULL OPEN
1.21 H_d AND 1.0 H_d
GATE 9 OPEN: 8.1 - 15.6 FT



CENTER LINE OF GATE BAY

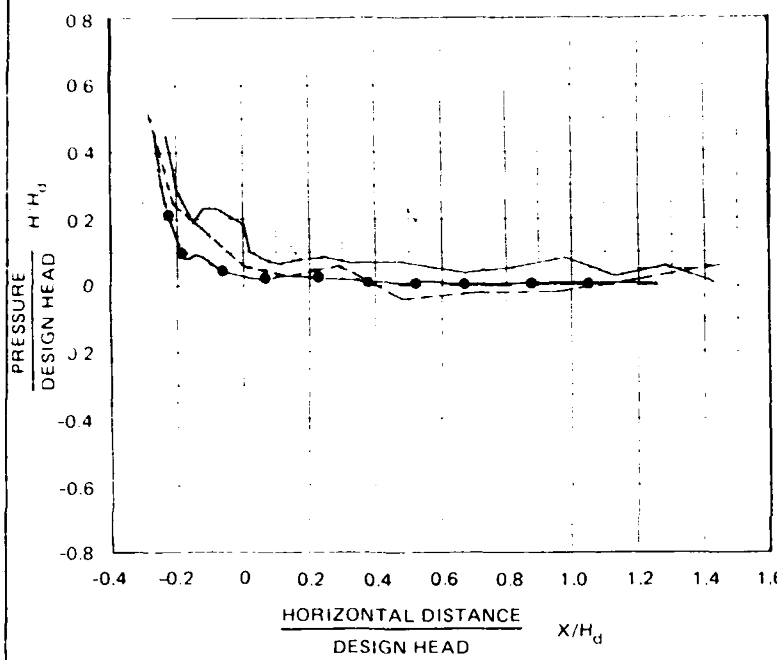


ALONG PIER

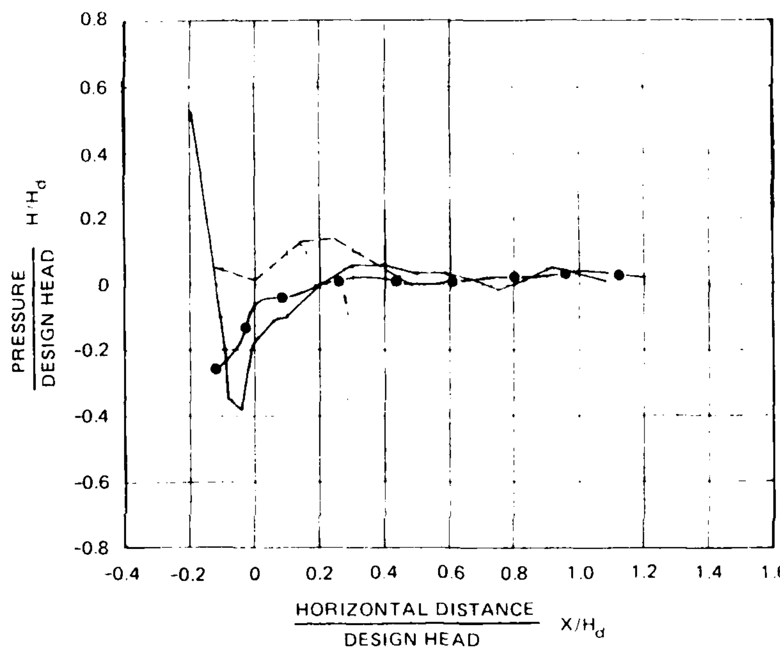
LEGEND

- – – – – PROTOTYPE DATA; $H/H_d = 1.31$
- ——— MODEL DATA (MAYNORD); $H/H_d = 1.33$
- —•—• MODEL DATA (MELSHEIMER & MURPHY); $H/H_d = 1.33$
- —x—x MODEL DATA (1979); $H/H_d = 1.31$

SPILLWAY CREST PRESSURES
ADJACENT GATE FULL OPEN
MODEL AND PROTOTYPE DATA
$H/H_d = 1.31$ AND 1.33



CENTER LINE OF GATE BAY

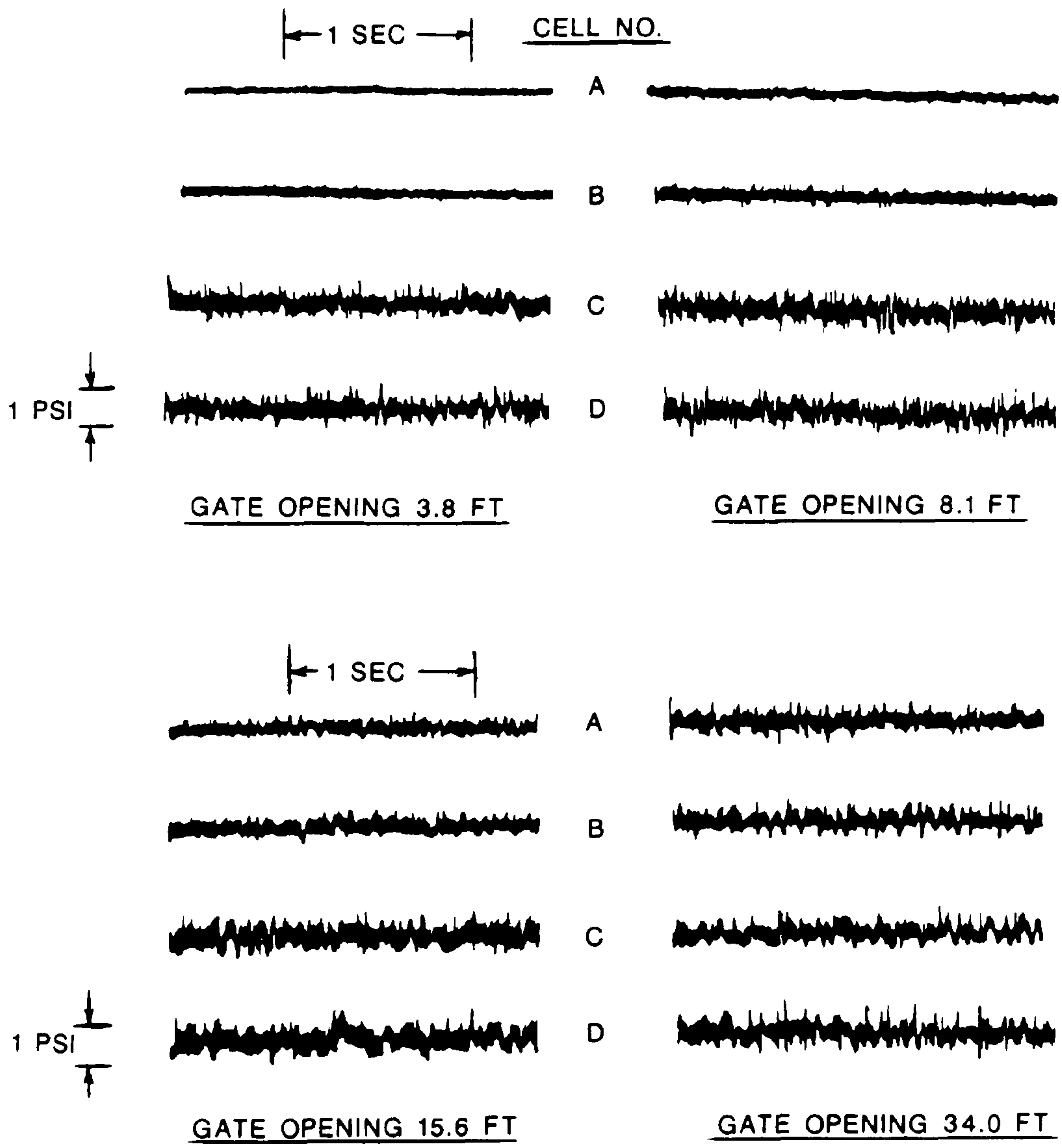


ALONG PIER

LEGEND

- - - - PROTOTYPE DATA; H/H_d = 1.21
—— MODEL DATA (MAYNORD); H/H_d = 1.17
-●—●- MODEL DATA (MELSHEIMER & MURPHY); H/H_d = 1.17

SPILLWAY CREST PRESSURES
ADJACENT GATE FULL OPEN
MODEL AND PROTOTYPE DATA
H/H_d = 1.21 AND 1.17



CREST PRESSURE FLUCTUATIONS
(H/H_p = 1.21)

END

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